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OUTLINE KEY TO TOPICAL INDEX

VOLUME XVI

THIS Index, as well as the previous indexes, is arranged according to the topical classification of subjects. original scheme for this method of indexing was published in the Journal for February, 1906. All articles which have appeared in the Journal since its initial issue can be located quickly by the use of the Ten-Year Index, (1904-1913), the Five Year Index (1914-1918) and the present Index, which covers the first year of the fourth pentad.

Abbreviations: *T*—Number of Tables; *C*—Number of Curves; *D*—Number of Diagrams; *I*—Number of Illustrations; *W*—Number of Words; *QB*—Question Box; *EN*—Engineering Notes; *EH*—Industrial Applications of Electric Heaters; *ROD*—Railway Operating Data. (The numerals following *EN*, *EH* and *ROD* are volume and page numbers.) The main headings and sub-divisions are as follows:—

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Post-War Engineering Problems

During the world war which has just been brought to a close by the defeat of Germany and her allies, doubt has often been expressed as to the benefits of the scientific achievement and efficiency brought about through the scientific and industrial research of the Germans during the last forty years. It is inconceivable, however, that such sinister use of science and invention could be deliberately planned and executed in a democracy such as ours. The fault has not been with the scientific advances but with the use to which they have been put. It is so plainly evident to those who have kept in touch with research, both before and during the war, that there must be a greatly increased activity in this line after the war, that such a statement to them sounds axiomatic. It may be well, however, to repeat and reiterate this statement until the truth becomes known to all our people and until we have at least a sufficient appreciation of what research can do for us that no one advocating the question will be called upon to explain why he is doing so.

We have learned many lessons through the work that has had to be done during the war and these should serve us well in the reconstruction period which is now before us. Among these lessons may be cited the following:—

We have obtained a better appreciation of what can be accomplished by co-operation and sustained effort for the solution of any specific problem, for example, the protection from submarines, or communication between aeroplanes, or the production of noxious gases for war purposes.

We have learned that certain industries almost entirely controlled by our enemies prior to the war can, through research, be established and maintained to advantage in our own country, making us independent of others in time of need.

We have learned that in many cases the handicap of high labor cost can be overcome by careful and systematic research. Many individuals have learned the joy of achievement in the creation and production of materials and devices required by the nation for its war program.

We are now faced with the necessity of so ordering our business in all walks of life as to be able to compete with other countries and the outcome of the peace negotiations may make it more necessary than ever that this competition be based on the quality and efficiency of our products rather than on some sort of government protection. It has become evident, to all who have studied the question, that the country which can produce within itself the greatest possible proportion of its requirements of raw materials and supplies is in the best position to meet competition in peace times and such production becomes vital in case of war.

Much as we desire universal and lasting peace, we are not yet in a position where this is guaranteed and we must keep, at least in the background of our minds, the possibility of future wars; and while we have no other object in view at this time than to promote the arts of peace, this object should be so achieved that we may take our proper place among the nations of the world. We can best assure ourselves of this place by a national program of research, or a program which will result in the training of large numbers of men fitted to do research work, and by so doing we will not only be preparing for our place in times of peace, but for any eventuality in case of the almost unthinkable catastrophe of our being involved in another world war.

C. E. SKINNER

What the Utilities Have Gained

How will the public utility business fare during the period of post-war reconstruction? One's first thought is that the term "reconstruction" applies more directly to the political and social changes that are imminently before us than to industry itself, for the latter is quite apt to be governed by natural laws which even a world war cannot affect very materially.

The central station industry has assuredly had its war burdens and will have them for some time to come. But no observer can escape the conclusion that the central station has gained more public recognition of its economic soundness and of its service potentiality than would perhaps have been possible during a decade of normal conditions. For we have seen the realization by the Government, by the financial world, by industry generally and by the public in particular, that in a crisis calling for the maximum employment of the Nation's resources, where the call was so imperative that each individual in more than a hundred million of population was required to give a personal account of himself, the central station was put way up at the head of the list with the army, with the navy, with the munitions, as an indispensable agency of national service.

And people will not forget this. In a myriad of ways it will prove to have been a public education in the importance to our communities and to the Nation of these great central sources of power supply. It seems, therefore, that we are bound to conclude that our public utilities have gained a good deal out of the circumstance

of the war, even if the economic conditions incident thereto have temporarily imposed heavy burdens upon them. One can think of few lines of business enterprise promising a more constant demand, assuring a more definite growth as the country grows, more legitimately entitled to earn if service be a measure of compensation, or more certain to attract investment on the basis of past and prospective performance.

E. H. SNIFFIN

Expansion of Railroad Electrification

During the past year, unquestionably the most important in the world's history, the potential increase of man-power has been the crucial effort of us all. We know, all too vividly, the narrow margin by which our men, supplies and equipment reached the other side. This has demonstrated effectively the hazard involved by inefficient methods of production and transportation and it has emphasized too the enormous price or penalty of unpreparedness. Preparedness properly involves analytical consideration of the past, the present and the probable conditions of the future. Preparedness, to be effective, must be supported by public opinion, this being the means by which, under our Government, all major situations are settled.

Our participation in the great war was determined by considerations of the future. It involved on the part of everyone much more reflection and serious thought than has ever obtained in the past. Perhaps the most valuable asset which will accrue therefrom will be the almost universal habit of such reflection and thought.

Fundamentally, we are zealous as a nation of the equality of the individual as to activity, recognition and advancement; that to those who deserve reward, just opportunity will not be restricted. This position, logically followed, insures inspiration for individual incentive which, if consistently carried out, will establish contentment and prosperity for the nation.

During the progress of the war, there has come to be recognized the necessity, and desirability as well, of greater compensation to the individual worker. This has been due to the increased costs of commodities, on account of their great demand and scarcity, and also to the desire to provide an incentive for speeding up or increasing the output of the individual. This latter condition has, unfortunately, not been realized due to the lack of universal response that would have been most desirable, but with the increasing habit of thought, it is hoped that this will be attainable.

In order to increase the productive capacity of the individual now so necessary to restore the depletion of the world's requirements, due both to destruction and the suspension of normal production, further recourse must be had to machinery. For its most efficient use, electricity, due to the ease and economy of generation, the facility of transmission and the flexibility of its application, is today the pre-eminent force for this service. Probably at no time in our history has the popular mind been so receptive to the advantages of the use of electricity as at present. Along with the more effective output per individual, of next importance comes the more efficient use of capital. Through the use of electric power, this will directly follow, due to the enhanced use of existing facilities.

Referring now to the railroad situation, it may well be considered whether, as a matter of right, the diversion of 25 percent of all the coal mined and of the transportation facilities necessary for its distribution as well, should be permitted to limit the use of fuel for household and productive necessities. A large part at least of the power necessary for the railroads could be obtained from water power now going to waste, or from steam-electric generating plants so constructed and located as to secure economy of fuel and of transportation. It is obvious that had electrification been general on the railroads, there would have been no such congestion or such loss to the whole country as obtained so dangerously during the past winter. Generally speaking, owing to the ability to use largely increased power for each train, together with the greater facility for movement, electrification will double the capacity of any railroad.

Consideration of the joint conservation of capital and the country's resources, as well as the more effective use of labor, leads, therefore, to the conclusion that the expansion of railroad electrification will be limited only by the ability to accomplish the construction and the provision of the necessary funds. This provision of funds must of course, be predicated upon the adjustment of corporate and legislative relationship which, through the "meeting of the minds", now more hopeful than ever, ought to obtain in the very near future.

F. H. SHEPARD

Post War Industrial Reconversion

The outlook for the electrical industry seems very bright for the period of industrial reconversion which will follow the war. It would be unwise to predict the future of any particular industry, but the ultimate results in any industry will largely depend upon the attitude of the leaders guiding it. If the various industries are guided with conservative optimism, as is the case with the steel industry, we may expect a continuance of industrial activity after a short period of readjustment. This activity will be necessary to provide the raw and finished materials to those industries curtailed on account of the war, such as structural steel for buildings, railroad equipment, automobiles, state and municipal improvements, etc. Also, although the manufacture of munitions will cease, many activities developed during the war will undoubtedly be continued to promote national progress; for example, merchant marine, aerial transportation, increased production of food stuffs, increased production of minerals, etc.

It would seem as though the demand for all lines of product will broaden in the near future, as it is only reasonable to suppose that the large commercial interests will follow the example of the steel companies

and formulate their plans in a manner to encourage the activities of business as much as possible. This should establish a feeling of confidence that is essential. With this condition existing there is no question as to the increased demand for electrical apparatus by industrial concerns, which in turn will naturally stimulate central station development.

The war has been a means of emphasizing to all users, both industrial and domestic, the fact that "power" means "electric power." Electrical apparatus and machinery have become an important factor in every industry and, therefore, will continue to be in demand, particularly since economical methods of manufacture will be more necessary than ever by reason of a world market. During the war, many plants were equipped with electric motors on an uneconomical basis, because existing apparatus had to be used to start production quickly, and undoubtedly many of these will have to be re-equipped for more economical operation. The next decade will see without doubt an unusual effort to produce industrial and domestic economies by the development of labor saving devices and these in nearly all cases will be electrically operated.

The program of improvements of industrial establishments has received attention during the last few years only so far as they were related to the demand for war products. Original plans have been modified, and while extensions have been made in some cases, it has been difficult to perfect new organizations. Time has been the principal factor in completing improvements and plans for power supply and new building were changed accordingly to meet this factor. Now that peace is practically assured, the present arrangement of machinery in many plants can be modified to advantage. In connection therewith central station service or power plant extensions must be given careful consideration with a definite comprehensive view of future growth and demand, instead of providing only for the particular expedient contemplated at any given time.

The shipbuilding industry, which has been organized on a large scale during the war period, must continue in order to replace ships that have been destroyed and also to provide greater means for export trade expansion. This field opens up a big demand for electrical machinery and apparatus, not only for constructing ships, but for equipping anxiliary apparatus on merchant ships, and providing docks with modern electrical devices for handling the cargoes quickly and efficiently. Considerable attention is being paid to this feature in order to reduce the time a ship is not actually moving cargoes.

The development of the chemical industry in this country during the war period has been very remarkable. Many chemicals previously purchased abroad have been developed at home and put on a commercial manufacturing basis. This success undoubtedly has encouraged further research regarding new uses of certain products, new products and new processes, nearly all of which involve the application of electricity.

There has been activity regarding electrification in the textile industry during the past years and though this industry was called upon for many war products, their electrical requirements probably would have been equally great for an equal increase in regular business demands. The prospects for further electrification seem very favorable.

The war has given a great impetus to the use of domestic electrical appliances and the smaller motor driven machines, due to the inability to secure household labor and the high cost of such labor. Prospects for the further use of these devices appear to be bright, because the buying public has become educated as to their convenience and are considering them as necessities rather than as luxuries. It is felt by some that many women, having taken part in industrial work, will wish to carry the ideas of efficiency applied in this work to the household, and they will appreciate much more than formerly the advantages of labor saving devices.

During the war, the manufacture of non-essential articles was practically discontinued. This trade will come back stronger than ever.

Public building, which has been practically discontinued during the war, will be resumed. This should reopen the market for heating and ventilating apparatus, elevators and other similar devices which are required for schools, colleges, hotels, office buildings, etc.

The development of individual generating sets for supplying electricity for light and power upon the farm has opened a large field. The use of these sets in the future will be very extensive, as the farmer is badly in need of anything that will save labor and improve working conditions. In those more thickly settled districts adjoining central station service lines, the use of individual generating sets will pave the way for the use of central station power in the future.

The standardization work started by the various war service committees, should put the electrical industry on a more economical basis and the enormous field for application to all industries is sufficient warrant for electrical manufacturers to be optimistic in their hopes as to the future of the industry. J. M. Curtin

Developing Our Electrochemical Resources A country richly endowed in natural resources is usually looked upon as wealthy, and rightly so, provided these resources can be made available for the needs of mankind, for only by developing them is it possible to realize on their value. A thousand tons of coal in the bunkers of a central station is of vastly greater worth to the stockholders and customers (the world at large) than an equivalent amount of coal unmined. Of course, without the original supply the question of availability does not arise, but given the original supply it becomes a factor of paramount importance.

On account of the vast extent of our mineral and

water power resources, America has come to be regarded as one of the most wealthy of nations, and it is now generally recognized that the chief factors in making possible the realization of this wealth are chemistry and electricity. The combination of these two primary forces—electrochemistry—is making available our vast store of mineral and power resources in the form of marketable products demanded by our daily needs, and the rate at which this development is proceeding is such that within the near future electrochemistry will be the largest single user of electric power. The term "electrochemistry" is here considered as including electric furnace and electrothermal processes, as well as those which are strictly electrochemical.

Even though America's pre-eminence along electrochemical lines has for a long time been internationally recognized, not even the most optimistic of her electrochemists could have predicted the tremendous expansion of this industry which the war has demanded. It is, however, now a matter of history that the electrochemical industry has been called upon to carry a large share of the war program, and practically every one of its better known products have been required in quantities far in excess of anything formerly produced. In this work our water power resources have helped to make available our mineral resources and the electrical engineer has worked hand in hand with the chemist.

To call to mind just a few of the better known electrochemical and furnace products, there may be mentioned ferro-alloys for the various high grade steels entering into munitions and war machines; artificial abrasives for manufacturing processes; aluminum for airplanes and truck motors; high grade electric steel for similar purposes; tremendous quantities of chlorine, used as the basis for all gas warfare; phosphorous and nitrates for explosives; calcium carbide (acetylene) for welding, cutting and for airplane dope; magnesium for light weight alloys and intensive illuminative purposes; immense quantities of alkali used in almost every industrial process; and so on down the list.

The old adage that "it takes fire to fight fire" has been well illustrated in this war, where we have been called upon to conquer a nation determined to make the war one of frightfulness and who, being well versed in the applications of chemistry, had determined to use all the vast resources of this science to excel the barbarians of early history with their molten metal, boiling pitch, stink pots, and firebrands, and by the use of modern chemistry produce a brand of heretofore undreamed of frightfulness. Chemists have been pitted against chemists, and suffice to say, we have matched our adversaries at every turn and have not only been able to produce instruments of destruction as effective as those of our enemies but, in many respects, were in a fair way far to surpass them.

By concentrating on the task, the much vaunted chemical leadership of Germany has been shown to be possible of equalization, and in the language of the slogan of the general engineering depot of the U. S. Army the old pessimistic cry of "It can't be done" has been answered through the optimistic perseverence of the chemist, the electrochemist and the engineer, by the reply "But here it is". By a short, hard sprint we have been able to overtake our adversaries lead. We now know that the seemingly impossible "can be done" for it *has been done,* and not only have we been able to produce those materials indispensible for war, but a vast number of the materials requisite for the carrying on of our industries, which were formerly imported, have been developed and are now being manufactured on a scale commensurate with our demands. For example, the supply of potash formerly obtained from Germany has been replaced through the work of our chemists and engineers by the potash of our lakes, rocks and seaweed, and that precipitated electrically from the waste gases of our cement mills and blast furnaces. Artificial dyes, 90 percent of which were formerly imported, have been replaced by over two hundred American made basic colors. The same can be said for many of our drugs and chemicals of commerce.

With the cessation of hostilities we have time to catch our breath and look about us in order to determine what future application shall be made of the facilities which have been created within the past few years and what further developments are necessary to make us chemically independent.

It is well known to those familiar with scientific and industrial history that new discoveries and inventions of merit which represent distinct advances have ultimately created their own demand, and that, although at the time of their inception they may have been commercially impossible of application, the fact that they opened the road for greater possibilities and achievements soon resulted in ways and means being developed for their general utilization.

Such products of the electric furnace as ferro alloys and high grade alloy steel, formerly considered too expensive—both in first cost and in cost of machining—although most desirable on account of mechanical characteristics, have been brought to a point where the increasing demands have made their use possible by the opening up of new sources of raw material supply, improved methods of extraction and of manufacture through the use of high speed (alloy steel) cutting tools and artificial abrasives. They have of themselves helped in making themselves available—they have met the market half way, and what a few years ago was a scientific curiosity is today a commercial commonplace. The net result of this is that the electric furnaces for the production of the high grade alloy steels must continue to grow to supply the demands of peace which can no longer be filled with an inferior product now that a superior one is available, (though even at a higher price) to which the market has been built up. Today's curiosity of the research laboratory is tomorrow's commonplace in the world's workshop.

Although detail information is still lacking, it is

a matter of common knowledge that many new discoveries of the research laboratories have been put into almost immediate use during the recent war. This will, of course, eliminate much of the usual time lag factor in their application to our industries. It now remains for us to select from our various war time discoveries and industries those which will be of greatest immediate value to the needs of our daily life under peace conditions and to find ways and means for the application of the excess manufacturing capacity of those products which the war demanded in quantities many fold greater than the previous peace requirements.

The American Electrochemical Society was one of the first to recognize the post-war future of the industry which it represents, and at its recent semi-annual meeting in Atlantic City this question was the subject of a symposium which brought forth animated discussion from many of the leading scientific and industrial men of the country. This whole subject has since then received wide consideration in other scientific and industrial bodies and, it is fully expected, will be the subject of investigation by an executive body appointed by the President.

Considering some of the more important electrochemical and electric furnace industries in detail, it is the consensus of opinion that the ferro-alloy and high grade steel industries will survive to the extent of almost 100 percent of their present development, and while certain situations involving high production costs may have to suspend temporarily, there is no question but that large developments will continue in other localities where conditions are more favorable. Quality of the product manufactured in an electric furnace has proven so superior that our industries will no longer do without it, and the manufacturers of what was formerly considered steel of a high grade have come to recognize that the electric furnace has advantages which cannot be obtained in the crucible. The ferro-alloys for the purification of ordinary steels, as well as for the manufacture of alloy steels have come to be considered indispensable. Even the long promised development of electric pig iron has been an accomplished fact for the past year or more, and further indication points to the continuance of this industry with the ultimate development of straight reduction from the ore.

In the nitrogen fixation field, the fertilizer industry apparently offers the most hopeful avenue for expansion, and the production of a highly concentrated product with the attendant reduction in freight charges gives promise of being a considerable boon to this industry. With our large productive capacity for nitrates, which it has been estimated will be almost double our usual peace time needs, it should be possible for us materially to reduce our importations from Chile and thus make available much needed shipping for other purposes. Present information is to the effect that two of the recently completed nitrate plants in the South are scheduled to be taken over by two of the largest chemical companies and applied to the manufacture of fertilizers and other peace time nitrates.

The realization by the farmers of some of our Middle Western States that the quality of the grain of those localities no longer measures up to former standards should be a strong incentive to the use of concentrated fertilizers produced by reliable manufacturers. Today in certain localities their use is almost an absolute necessity. The fact that we will be called upon to supply much of the food for Europe during the next few years is a further incentive for the intensive cultivation of our fields by the use of high grade fertilizers.

The problem of using our tremendous productive capacity for chlorine in peace times is perhaps the most serious one facing the electrochemical industry. Unquestionably, there will be an overproduction for some time, but with the widespread and constantly increasing variety of uses for this element and its compounds, the ultimate solution of this problem should be possible. One suggested peace-time application of a small portion of our poisonous gas plant capacity is for the manufacture of certain of these gases for use in the treatment of bugs and vermin destructive to plant life.

The use of alkalies is so universal, entering as they do into almost every industry, that the peace-time application of our productive capacity in this line is not a problem of such serious moment as those mentioned above.

Aluminum is so widely used that the present productive capacity does not present a difficult peace-time problem. The same may be said for artificial abrasives, graphite, carbon electrodes and other electrochemical and furnace products.

Closely related to the problem of using our recently developed facilities is that of so co-ordinating and interlocking the work of our chemists and engineers as to insure the ultimate development of our chemical independence of foreign powers. The first step in this problem is a national stock-taking or inventory, such as the chemical survey proposed by Dr. Hesse in a recent issue of the *Journal of Industrial and Engineering Chemistry*, in which is recommended a complete listing of our manufactured products and the raw materials they require, our imports and their requirements of raw materials, and the co-operation of the Geologic Survey to help locate raw materials needed for extension of our chemical manufacturing. With such information at hand, the more important problems can be listed. In the meantime, with the spirit of national co-operation so prevalent at this time, it should be possible to co-ordinate the work of our research laboratories, particularly those of our American Universities, placing their work under the direction of governing boards composed of representatives of each laboratory or university, perhaps grouping those in adjacent localities under local boards and these under one general board. It will thus be possible to attack the major problems simultaneously along predetermined lines with the assurance of quicker and more complete solution and the elimination of a vast amount of effort often wasted through lack of complete facilities, or misdirected through ignorance of work already done or being carried on by a rival

institution. Only by such organization can our chemists and engineers be welded into a working unit, with a minimum of friction and wasted energy, which can ultimately point the way to true national independence.

The cessation of hostilities presents the problem to our electrical engineers and chemists of producing many materials at an economical cost which during the war were considered largely on a quantity basis, regardless of cost. Foreign competition will be met and the industries must be co-ordinated just as the research laboratories already discussed, so that the byproducts of one may be utilized without waste by the other. With the national chemical awakening which we have had and with the closer association of our chemists, as a result of their work in the Chemical Warfare Service and of our engineers in the U. S. Army Engineering Corps, this long recognized problem should be readily possible of solution.

Having the lessons brought home to us by the war fresh in our minds, and with the consequent popular realization of many of those problems long apparent to scientific and industrial leaders, it is now possible for us to pull together toward a 100 percent utilization of the tremendous opportunities which the wealth of our country presents to us. C. G. SCHLUEDERBERG

Post War Steel Conditions The steel trade is generally considered as a barometer of business conditions. Accepting the steel business as constituting almost the backbone of modern industry, it is encouraging to note the optimistic attitude with which the steel trade papers discuss the question of business adjustment following the war. Such leaders as Judge Gary and C. M. Schwab have expressed very optimistic views regarding future business in the steel industry and believe that much good can be accomplished by a concerted display of confidence by business men in general, and prompt action in preparing for normal conditions, based on this optimistic opinion. Naturally, one company's plans involve the interest of many others, and the gain in business momentum to counteract the cancelling of contracts and general hesitation to purchase with the idea that prices will be materially lower in the near future, will be greatly accelerated if all business men recognize conditions and conduct their different lines of industry so as to adjust the question of supply and demand on a legitimate basis, thus preventing any abrupt and unwarranted price disturbances. A stabilized market will do much towards re-adjusting business to a sound normal basis.

There are many indications that warrant an optimistic opinion regarding future business conditions. The steel trade is on a very sound basis. The companies are strong financially, general conditions regarding supplies of materials, ore, coke and coal are favorable, transportation presents fewer problems as compared with the last two years, and labor will soon be sufficient for all demands. Many industries whose regular manufacturing programs have been curtailed by the war are again coming into the market for steel, and steps have already been taken by the steel trade to stabilize market conditions. Such action should be of material assistance in preventing any prolonged hesitancy on the part of other manufacturers to proceed with improvements.

Many improvements and modifications in the steel plants themselves will be necessary in the near future, as all such changes in the immediate past have been made solely with a view toward meeting war conditions, and the present arrangements in many cases can undoubtedly be modified to advantage with a change to normal times.

It has been demonstrated clearly that electrification of rolling mills furnishes one of the most advantageous means of improving plant operating economy. There are now more than 500 large motor drives on rolling mills of every type, including about thirty reversing mill equipments. During the unusual requirements of the war period many demonstrations have been made of the advantages of electric drive, including the flexibility of operation as offered by adjustable speed equipment, and the specially favorable speed torque characteristics of electric units. Many unusual records have been established in electrically operated mills, and with the return to normal times, the steel trade should be in a very good position to take advantage of this valuable experience, and make thorough investigations regarding the best method of operating the mills.

One of the principal developments of recent years has been the reversing mill motor equipment, whose success has been marked. Many mills of recent design include a reversing roughing stand and a tandem arrangement of the mill, which gives the plant greater flexibility of size of product and increases the tonnage, with a decrease in power requirements. Unlike the steam drive, which requires an unusually large steam supply for a reversing equipment, the reversing motor drive acts as an equalizer for the three-high, continuously operated mills, since the power taken from the supply line is quite uniform for the former and is intermittent with high peak loads for the latter type of mill.

Many plants have installed electric furnaces for the manufacture of ferro-alloys, one of the principal products being ferro-manganese. These alloys were used largely in steels manufactured for munitions and guns, and as such requirements are now greatly reduced and the general steel market is changing to a more normal basis, the majority of these furnaces will be changed to more commercial products. For example, electric furnaces have been extensively used for the manufacture of nickel steel for gun forgings and manganese steel for helmets. Such production will be changed over to more normal lines, including steel for castings and alloy steel for machine parts, such as those required for automobiles and other machines. Seemingly, the special steel market has a good future, as the trade in general are now much better educated regarding its advantages and possibilities than they were a few years ago.

Many plants have found it advantageous to analyze their power requirements and future improvements from a complete plant standpoint, thus giving to each individual mill proposition the benefit of its relation to the entire plant, and thereby properly distributing the general charges. This plan enables the advantages of the motor drive to be capitalized as a part of the general scheme of improvement. Viewed from this standpoint it is recommended that the steel companies study their readjustment period plans with the idea of developing a general plant improvement, and that they analyze their individual mill propositions on this basis; for when the individual mills are analyzed as segregated propositions the summary of the advantages of motor drive does not establish the true over all plant efficiency. For instance, the question of power plant extensions should be studied with a definite view of future plant capacities, instead of merely providing for the particular improvements contemplated. It is extremely important that the power requirements be provided for in advance of actual demands. One of the noteworthy features of recent practice is the selection of large size turbine units. This tends to improve the efficiency of power production, as the water rate of the larger units is materially better. A few years ago a 3000 to 4000 kw turbine was considered a large unit for a steel mill installation. At present units of 15 000 to 20 000 kw are being considered, whose unit steam consumption, by reason of the larger size and improved operating conditions, such as higher steam pressures, higher superheats, etc. is but little over half that of the smaller units.

A more common use of central station power has been adopted during the war period in particular. It has been a factor in facilitating installations and also offers many advantages of reduction of first cost of operation and permits of greater flexibility of plant layout for future improvements. More than fifty percent of the motor equipments installed during the last two years use central station power and more than 60 percent are 60 cycle units. The tendency towards the adoption of 60 cycle apparatus as a standard is very marked.

Brent Wiley

Munition Work in Pittsburgh

The article by Mr. T. D. Lynch, in this issue of the Journal, is descriptive of one of the latest shell machining plants in the Pittsburgh district. The plant at Shadyside, which was formerly devoted to the manufacture of automobile equipment apparatus, at the urgent request of the Ordnance Division of the War Department, was converted into a shell machining plant. This is one of six plants which the Westinghouse Company organized wholly for munitions work. Naturally, being the latest, it is the most up-to-date, and is capable of a daily output of 3000 six-inch United States high explosive shells. The Company started with shell machining work in 1914, and was one of the first organizations, if not the first, outside of regular ordnance companies to undertake shell production, the Company's first contract being made with the British Government late in 1914. The work which has been done has covered all characters of shells, from the small 13-pounders to 15 inch naval shells weighing approximately 1800 pounds.

During the time the work has been going on, approximately six million shells have been produced and shipped, and the work has proceeded almost uninterruptedly (except for a short period during the summer and fall of 1917) since its inception. The value of the product which has been turned out and shipped in the period approximates $130 000 000 to $140 000 000, when account is taken of the value of materials as well as the labor which enters into the product. This production has given work to thousands of people in the Pittsburgh district, many of whom would have been out of employment during the earlier years of the war, because of the slack times then existing in industrial lines.

In addition to the shell work, the Company has assisted in the development of various types of grenades and grenade dischargers and has manufactured five million United States Government rifle grenades and several hundred thousand grenade dischargers.

The present description of the various operations necessary to transform the rough forgings into finished shells gives a general idea of the amount of equipment and the extent of the problem of organization and administration involved in the production of large quantities of finished shells for, simple as the shell appears in its finished condition, it has to meet requirements of inspection and test from operation to operation of manufacture, as to accuracy of dimensions, weight, volume and physical properties almost approaching perfection.

H. P. Davis

Insulator Characteristics

The insulator has always been the weak element in a transmission line. Anything therefore that improves its dependability and therewith the reliability of the transmission and distribution system which it supports, is of the utmost importance to the electrical industry.

The cost of the insulators on a transmission line depends not only on the price of the units, but also on their characteristics. Freedom from breakdown and breakage and relative freedom from deterioration with age means reduced replacement expense, and with many operating companies this feature is of greater importance than the initial price. Improved mechanical characteristics permit longer spans and hence fewer insulators. Aside from the direct saving produced by a higher quality of porcelain, the value of uninterrupted service is beyond computation.

The article in this issue by Messrs. Gilchrest and Klinefelter is the last of a group of five, which analyze the theoretical and ceramic problems which enter into the design of porcelain insulators, and adapt the results to agree with the service experiences of operating engineers. The result of the investigations described has been to eliminate to a large extent the old cut and try methods of insulator design and manufacture.

Chas R. Riker

Application of Theory and Practice to the Design of Transmission Line Insulators

G. I. Gilchrest and T. A. Klinefelter

The theoretical elements of the problem which laid the foundations for the following developments were outlined in previous issues of the Journal.* The present article** deals, for the most part, with laboratory tests of various new designs and a comparison of these designs with those now in commercial use.

USUALLY any design problem of engineering may be quite easily separated into two rather distinct phases. The one phase is termed "theoretical" and infers that the service experience, processes of manufacture, cost of materials, cost of manufacture, etc., are placed secondary in importance in the search of an ideal design. The other phase is termed "practical" and infers that the design has been evolved mostly from a consideration of service experience. It is generally conceded that a design evolved by either method may have certain advantages. The object of the following investigations has been to link together these two phases in a specific application, namely; the design of pin-type transmission-line insulators.

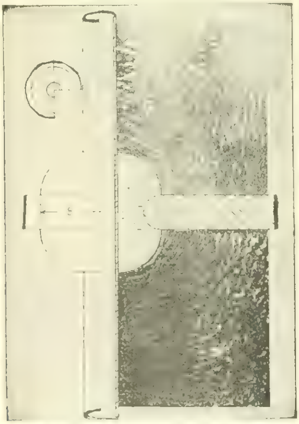


FIG. 1—FIELD FORM OF BUSHING

Having dimensions of ring and rod chosen such as to give maximum breakdown voltage over the surface for the mean diameter of torus ring.

Two logical questions at once arise:—

First, are the insulator designs installed in service at the present time satisfactory?

Second, can one type of design be developed that will be satisfactory in all localities?

The first question is answered by a resume of current engineering literature, which offers convincing evidence that there is a field for improvement. A comparison of the flashover voltage versus overall dimensions and weight of the present insulator designs would seem to warrant an attempt toward uniformity. Furthermore, the divergence of certain characteristics of some designs from the average curves indicates that some of the designs must be far from efficient.

The causes of such chaos in insulator designs are quite obvious. First of all, the progress in transmission engineering has been rapid. The expanding transmission companies demanded insulator designs which would offer a good factor of safety. There was no previous operating experience to use as a basis in new developments and consequently it was often necessary for the transmission engineer to propose his own design. Moreover, the majority of our present insulator types were designed when the electrical and mechanical characteristics of porcelain were less understood than at present. As a result, various features were accentuated

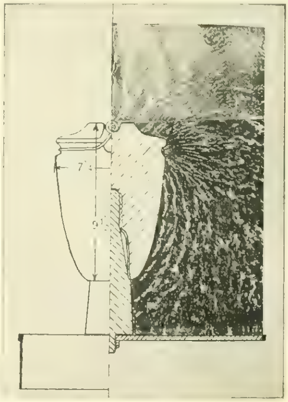


FIG. 2—DIELECTRIC FIELD

About line insulator without rain sheds.

as most important. That is, at one period a long leakage path was required, regardless of voltage distribution per shell from capacity current or leakage current; then again a high puncture voltage, then a high mechanical strength, and so on. Naturally, many mistakes were made and a large proportion of the older insulator designs have failed in service application.

CAUSES OF INSULATOR FAILURES

The knowledge that certain insulator types have failed in service is of little value in the redesign of insulators unless actual conditions of service and cause of failure are known. Also, the cause of failure of a particular type in one locality should be compared to the cause of failure in other localities. Hence, before attempting to develop a new type of design, a study was made of available data on insulator deterioration and

*In the Journal for February, p. 36; March, p. 77; and November, p. 443, 1918.

**Revised by the authors from a paper before the American Institute of Electrical Engineers, June 1918.

the opinions of operating engineers in various parts of the country were obtained.

From these discussions, from published data on insulator deterioration, and from observations of insulators that had failed in operation, it would seem that the following are the main causes of failures:—

1—Improper distribution of dielectric field.
2—Improper distribution of surface leakage.
3—Porosity.
4—Mechanical breakage. (a) From handling. (b) Mischievous shooting and stone throwing. (c) Insufficient strength as a support. (d) Brittle material.
5—Lightning.
6—Birds and animals short-circuiting the line.
7—Unequal expansion of metal, cement and porcelain.
8—Internal stresses in the material.
9—Defective batches.

Items *3*, *4(d)* and *9* are the problems of the ceramic engineer, rather than of the designing engineer. These items have doubtless been of great importance in the past, but more scientific and painstaking factory control must minimize them in the future.

It was believed that the data previously outlined, in conjunction with the available data of other investigators* of both an analytical and experimental nature, afforded sufficient basis from which to formulate preliminary designs. Hence, several theoretical insulator designs were produced out of a usual commercial porcelain body. The dielectric field of these was then investigated under a voltage of approximately the same value that would be impressed in service. Thereafter practical considerations, such as deterioration of the various commercial units in service, manufacturing limitations, etc. were taken into account, with the resultant design described later.

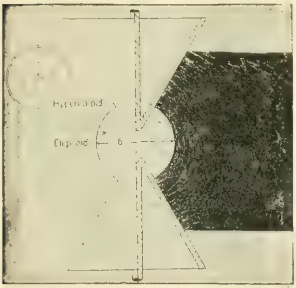


FIG. 3—DIELECTRIC FIELD ABOUT THEORETICAL DESIGN
Using confocal surfaces of revolution.

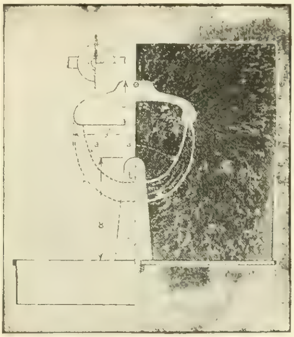


FIG. 4—SPECIAL CAP AND PIN
Such as might be used as terminals of a line insulator.

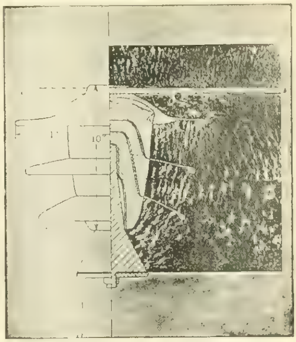


FIG. 5—DIELECTRIC FIELD
About insulator with metal rain sheds.

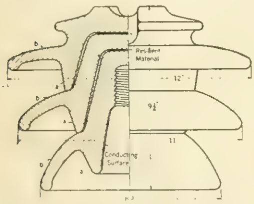


FIG. 6—THREE-PIECE INSULATOR OF THE PROPOSED TYPE OF DESIGN—INSULATOR *A*

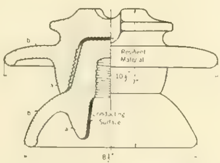


FIG. 7—TWO-PIECE INSULATOR OF THE PROPOSED TYPE OF DESIGN—INSULATOR *B*

*"Distribution of Potential about High Voltage Line Insulators," by C. T. Allcutt and W. K. Skolfield, in the *Journal of Electricity, Power and Gas*, June 17, 1916. "Electrostatic Problems," by C. W. Rice, in the *Trans. A. I. E. E.*, Vol. XXXVI, 1917.

METHOD OF DETERMINING FORM OF DIELECTRIC FIELD

The dielectric field was determined by the following procedure:—The insulator was fastened in a position such that the plane of the field to be determined extended horizontally. A piece of fullerboard was fitted over a half section of the insulator in this plane. In all cases the cross-arm supporting the insulator was grounded as in service where steel construction is used. Finely divided asbestos was then sifted evenly onto the sheet of fullerboard, voltage at 60 cycles of the desired value was applied, and the sheet was gently tapped until the particles had adjusted themselves. Permanent records were obtained by placing a sheet of photographic printing paper over the fullerboard, obtaining the field as above, and exposing the paper after the particles had become arranged. That the stronger portion of the field around an insulator was not disturbed materially by the presence of the fullerboard or the asbestos particles was proven by suspending a piece of finely drawn glass in parts of the field by means of a silk fibre supported by small insulated rods. As nearly as could be checked, the glass indicated the same direction of the field as the asbestos particles.

THEORETICAL INSULATOR DESIGNS

The dielectric fields of five theoretical designs were determined. Wherever a customary transmission cross-arm and linewire are used, there are two principal planes of the dielectric field which show the greatest difference, *i.e.*, the plane of the cross-arm and the plane of the line wire. These two planes are 90 degrees apart and in passing from one to the other the transition is gradual. During the investigation, records were taken of the dielectric field for these two principal planes and of a plane midway between the two. The plane in

which the particular field was taken is indicated by the reduced top projection at the upper left portion of each figure.

DIELECTRIC FIELD FORMS OF THEORETICAL DESIGNS

The direction of the electrostatic field about various theoretical designs is shown in Figs. 1 to 5, while Table I gives the length of path over the insulator surface between electrodes and the 60 cycle flashover voltage.

TABLE I—INSULATOR CHARACTERISTICS

Shape in Figure	Length of Surface		Effective Kilovolts Flashover Voltage		
	Inches	Cm.	Total	Per Inch	Per Cm.
1	4.25	10.8	87	20.4	8.1
3	6.5	16.5	148	22.8	9.0
2	8	20.3	115	14.4	5.7

From a consideration of Table I it is evident that a flashover value of between 20 and 23 kilovolts per inch (8 and 9 kilovolts per centimeter) of surface may reasonably be expected if the unit is designed with contours of the surfaces approximating the flow lines of the dielectric field. Of course, the flashover on the unit without rain sheds, Fig. 2, is somewhat lower, being 14.4 kilovolts per inch. The lower flashover on this unit is due to two conditions, *i.e.*, the porcelain surface does not follow the dielectric field in all planes and the small tie wire produces corona and subsequent static discharges at a relatively low voltage. Placing a static shield on the top of this unit increased the flashover voltage 18 percent.

With the field form between cap and pin as given in Fig. 4, and the voltage values given in Table I, theoretical insulator designs could be determined for such electrodes. Such designs should follow the surfaces indicated on Fig. 4, as (*a*) and (*b*). The highest flashover voltage for a given surface distance between electrodes would thereby be obtained. Moreover, the flashover voltage of such a unit could be closely approximated if the electrodes have sufficient radius of curvature at points of contact with the insulating material and a good seal is made between the metal and the insulating material.

FIG. 8—DIELECTRIC FIELD AROUND INSULATOR *C*

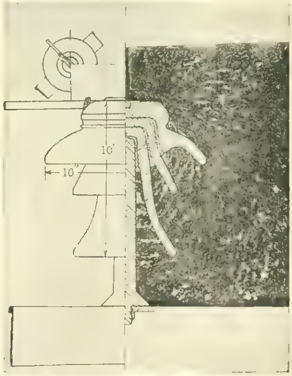


FIG. 9—DIELECTRIC FIELD AROUND INSULATOR *D*

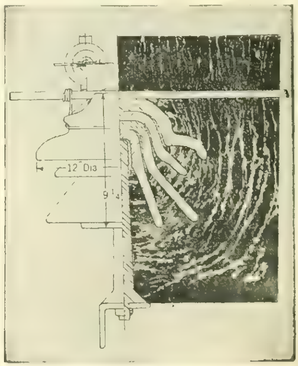


FIG. 10—DIELECTRIC FIELD AROUND INSULATOR *E*

MODIFICATIONS OF THEORETICAL DESIGN TO MEET OPERATING AND MANUFACTURING CONDITIONS

Insulators based on such theoretical data would be excellent from the electrical and mechanical standpoints if they were to operate in clean, dry air. However, the commercial insulator must maintain the transmission system during the heaviest of snow and rain storms. Moreover, it must have sufficient leakage distance to prevent flashover or even high power loss from surface leakage when the surface becomes dirty and wet.

The production of one-piece insulators for high-voltage service, although possible, would be costly. Also, the puncturing voltage of a one piece unit would be low for a given thickness, since the stress in an insulating material between metal electrodes of different potential varies as a logarithmic function. The separation of the unit into parts that are cemented together, more uniformly distributes the stress of the dielectric if the unit is properly designed. It also decreases the probability of complete failure of the insulator and facilitates factory production, lessening the cost of the commercial unit.

The use of a special cap would be desirable from a dielectric standpoint. However, the voltage characteristics under rain are the same whether the usual line and tie wire or a special cap is used. Moreover, the cost and ease of replacement, cost of construction, etc., favor the line and tie wire construction.

PROPOSED COMMERCIAL INSULATOR DESIGN

With the above limitations of the theoretical designs and the causes of insulator failures in mind, the type of unit indicated in Fig. 6 was evolved.

Summed up briefly this type of design embodies the following features:

1—The surfaces *a* conform to the flow lines of the electrostatic field.

2—The surfaces *b* of the rain sheds conform to the equipotential surfaces.

3—The lines of mechanical stress are parallel to the electrostatic flow lines.

4—The leakage resistance per shell is about equal, being increased gradually from the head to the center shell.

5—It has approximately equal capacity per shell.

COMPARISON WITH OLDER DESIGNS

It is not possible to much more than indicate in the following discussion the methods employed to compare the proposed type of design given in Figs. 6 and 7 with the older commercial insulators. Samples of various commercial designs were produced and were subjected to rather thorough laboratory tests at the same time tests were made on insulators of the proposed design. It should be noted that the insulators of the new type used in the comparative tests do not exactly correspond to the proportions of Fig. 6. In order to lessen the cost of investigation, insulator sheds of several diameters were obtained from one set of molds by trimming the individual shells before burning. This also accounts for the unfinished appearance of the edges of the sheds, etc., in some of the experimental designs.

In the following comparison it is not assumed that the evolved design should be final in each detail. The main goal toward which work is being directed is uniformity of all the elements entering into the designs with the idea in view of arriving at a type of design which will be equally successful in resisting failure in service whatever the requirements are in that particular section. In the following comparisons the items causing failure in service are discussed in the order given at the beginning of the paper.

1—Dielectric Field Distribution—The shortest air path under electrostatic stress should be at least long enough to prevent overstressing of the air at any point. In the previous theoretical discussions it was proved that wherever porcelain and air are in series in a dielectric field the voltage gradient per unit distance through the porcelain will be ¼ to 1/5 the voltage gradient through the air. It is obvious that any thin section of air between porcelain sheds of a customary line insulator will be over-stressed even at the normal line voltage of the insulator.

In order to make a comparison of the dielectric fields of various insulators, their field forms were determined as in the investigation of the theoretical designs. It is believed that the following field forms and illustrations, Figs. 8 to 20 inclusive, sufficiently indicate that many present types have not been designed with a full appreciation of the advantages of shapes that conform to the electrostatic flow lines in obtaining the most efficient distribution of the stresses in the dielectric field.

Fig. 8 (insulator *C*) gives the dielectric field of a unit of the type used in the early developments of high voltage transmission. The air between sheds just below the cement section is highly stressed. Because of the height of the pin in proportion to other dimensions of the unit the stress toward the base of the pin and the suporting cross arm is very low. Moreover, the third shell of the insulator is spaced so close to the insulator pin that it does not take its proportion of voltage stress when either dry or wet flashover occurs.

Fig. 9 (insulator *D*) shows the dielectric field of a three piece insulator of a somewhat more recent design. The center shed is better spaced than in insulator *C*. However, the air just below the cement sections is highly stressed and the short rain shed of the second shell gives an unequal voltage distribution at flashover, dry or wet.

Fig. 10 (insulator *E*) shows the dielectric field of a four-piece unit of comparatively recent design. The sheds of this design are more uniformly spaced, but the air between sheds just below the cement sections is highly stressed. The stress throughout the dielectric field of this unit is an improvement over the types *C* and *D*. However, the short second shed and protected fourth shed give unequal voltage distribution at flashover dry or wet.

Fig. 11 (insulator *F*) shows the dielectric field of a unit of the proposed design. The shortest air path between shells is sufficient so that the air is not overstressed at the working voltage of the insulator or until flashover occurs. Moreover, the rain sheds are so

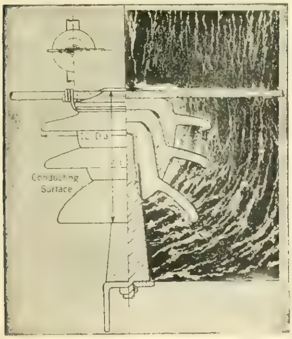


FIG. 11—DIELECTRIC FIELD AROUND INSULATOR *F*

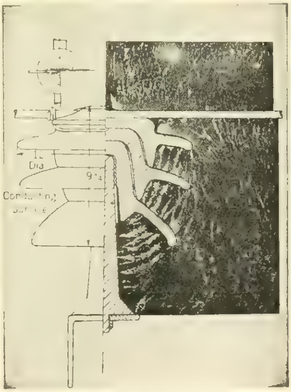


FIG. 12—DIELECTRIC FIELD AROUND INSULATOR *F*
With the upper surfaces of the rain sheds covered with a conducting paint.

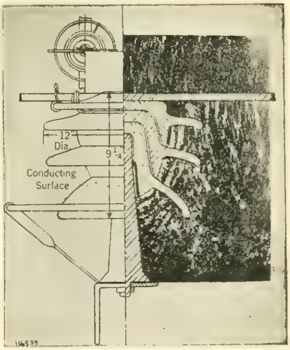


FIG. 13 DIELECTRIC FIELD AROUND INSULATOR *F*
Equipped with Nicholson arcing rings.

spaced that each section of the unit takes its share of the stress at flashover, dry or wet.

Fig. 12 shows the dielectric field of insulator *F* having the upper surfaces of the rain sheds covered with a conducting paint. This field form, which approximates the rain conditions, indicates that the stress per shell on the unit during rain would be approximately equal. Moreover it indicates that the stress in the dielectric field is more uniform during rain.

Fig. 13 shows the dielectric field of insulator F when equipped with Nicholson arcing rings, and indicates that the most highly stressed portion of the field about the insulator is not changed. However, the most highly stressed portion of the field between the line wire and the cross arm is now between the arcing rings and flashovers would, therefore, occur between the rings.

Fig. 14 shows the dielectric field of insulator *F* when static shields are placed at the top and base of the

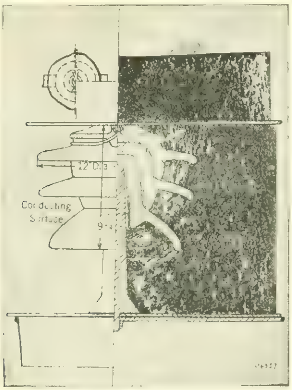


FIG. 14—DIELECTRIC FIELD AROUND INSULATOR *F*
With static shields at top and base of the insulator.

insulator. This combination would give a very fine distribution of stresses in the dielectric but would be rather expensive commercially.

60-CYCLE FLASHOVER TESTS

Flashover on most of the older insulator types is caused by the corona formation at the line and tie wires and the edges of the cement joints between shells. As the voltage applied to the insulator is increased, the area of the corona formation increases and static streamers gradually spread over the surface of the insulator sheds. The static streamers increase in length until the air insulation between them finally fails and flashover follows. Obviously, the path of the flashover will start along the path of these streamers. Trouble may thus be caused by the intense heat of the power arc and the rain sheds may be stripped from the insulator.

In the proposed type of design there are no static streamers from the edges of the cement section between shells up to flashover voltage. The corona formation at the tie and line wires therefore, builds up until flashover occurs by breaking down an air path between the line and pin or cross arm. The proof of these statements may be seen in the following illustrations. The axes of the two units in each of Figs. 18, 19 and 20, giving comparative flashovers, were at the same distance from the camera lens and hence the dimensions are directly comparable.

The difference in the stress in the air around the insulators just below flashover voltage dry was very marked. Insulators of the proposed type, *F*, *G* and *I* in Figs. 18, 19 and 20, showed no appreciable corona except at the line and tie wires until flashover occurred. Static streamers began to spread out over the surfaces between sheds of insulators *H* and *J* at 80 percent flashover voltage and the arc therefore formed over the insulator surface. Of course the old type design in Fig. 20 has been entirely superseded, but it clearly indicated the entire neglect of a consideration of the dielectric field.

The difference in distribution of stress before wet flashover is even more noticeable. In insulators *H* and *J* the unequal spacing of rain sheds, combined with a highly stressed air between the sheds below the cement sections, produces preliminary discharges (marked *p*)

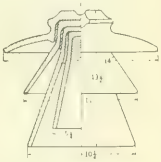


FIG. 15—INSULATOR *J*

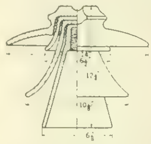


FIG. 16—INSULATOR *K*

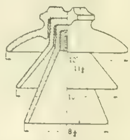


FIG. 17—INSULATOR *H*

between the sheds. These preliminary discharges throw electrical impacts onto parts of the insulator and short circuit portions of the porcelain between the line and pin. Consequently, when a line surge occurs during a rain storm or when the unit is wet and dirty, the factor of safety of these insulators in resisting puncture or flashover is actually no more, and sometimes is less, than it would be minus one of the shells.

Insulators *F*, *G* and *I* of the proposed design show no preliminary discharges except static from the tie or line wires to the pin or cross arm. Static discharges (marked *s*) are shown in Fig. 19. All of the leakage surface and the thickness of porcelain between the line and the pin, are, therefore, effective up to failure by flashover.

2—*Surface Leakage*—Table II gives the resistance per shell of various insulators tested during this investigation. The values were obtained by an integration of the surface, *i.e.*, surface resistance equals $\int \frac{ds}{2\pi y}$ where $d\,s$ is an element of surface and y the radius of that element from the axis of the insulator.

It is obvious from Table II that certain of the older designs especially those having a short second shell, long inner shells, etc., have a very unequal surface resistance per shell. If the insulator surface becomes dirty and wet, so as to pass a leakage current of even a thousandth of an ampere, the voltage distribution would depend

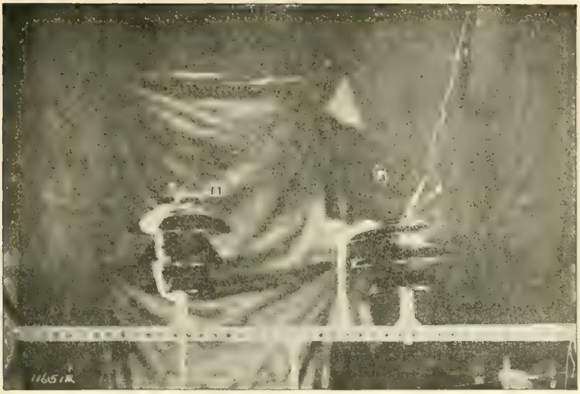


FIG. 18—60 CYCLE DRY FLASH OVER ON INSULATORS *G* AND *H*
The design of insulator *H* is shown in Fig. 17.

FIG. 19—60 CYCLE WET FLASH OVER ON INSULATORS *J* AND *I*
The design of insulator *J* is given in Fig. 15. Insulator *I* is of the proposed type similar to the unit shown in Fig. 6.

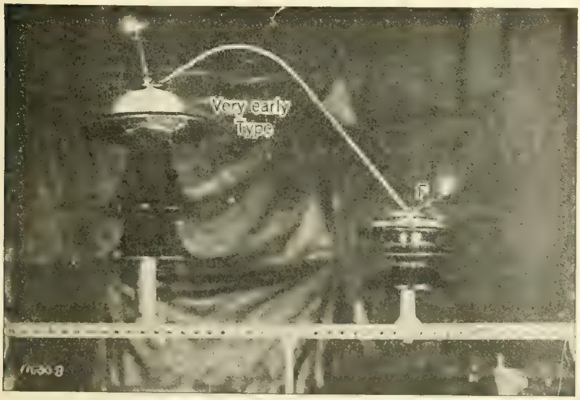


FIG. 20—INSULATION *F* IN PARALLEL WITH A UNIT OF EARLY DESIGN
Showing the corona formation and static discharge over the head and between the head and second shell of the old type unit. The camera exposure was 45 seconds at F-8.

upon this current and the capacity current could be neglected. The voltage gradient over the insulator surface thus often becomes sufficient to cause discharge between the sheds and pin or cross arm or over the short sheds. An electrical impact is thereby applied to parts of the insulator and portions of the porcelain body between line and pin are short circuited. It is believed that the continued overstressing of parts has been the cause of many insulator failures in the past.

The surface resistance of the proposed designs as typified by insulators *A* and *B* in Table II is gradually increased from the top to the center shed, the increase being considered as an advantage, since the center sheds will usually become dirtiest.

A novel feature of the proposed design is illustrated in Fig. 21 showing insulators *D, E, F* and *H*. These units were set on a cross-arm, line and tie wire attached as in

TABLE II—SURFACE RESISTANCE PER SHED IN PERCENT OF TOTAL RESISTANCE

Insulator	Number of Shed			
	First	Second	Third	Fourth
A	28	30	42	..
B	45	55	..	..
E	14	13	32	41
F	26	29	45	..
G	26	31	43	..
H	18	29	48	..
I	12	16	32	40
K	15	11	30	44

service, voltage applied and plaster of paris dust blown around them. The surfaces along the lines *a* of the proposed design (Fig. 6) are practically free of dust.

The reason for this is quite apparent. All the force acting in the dielectric field along this surface *a* is tangential and would tend to force the particles to the sheds above or below. The same action was noted when the units were subjected to atomized salt water. This feature would doubtless have some value in dust laden sections since the dust would tend to settle mostly on the lower shed and rain and wind would clean this to some extent.

It is necesary to clean the insulators in long portions of line in certain sections of country as the coast districts of California. It is very apparent that the proposed type of design may be cleaned much more readily and thoroughly than any of the older types.

3—Porosity—The deterioration of porcelain insulators in service was given little consideration during the early days of transmission engineering. The majority of transmission engineers preferred an insulator having a porcelain body which offered a high resistance to mechanical breakage. As a consequence,

the porosity of the material, which varies inversely with the mechanical strength as regards resistance to mechanical impact, was considered of secondary importance. The results that this condition have caused in service have been clearly presented.* Since porosity is a function of the body compositions, manufacturing processes and burning, more scientific and painstaking factory control must minimize its effect in the future.

4—Mechanical Breakage—(a) From Handling: The increase of thickness of the rain sheds and addition of a drip edge will materially decrease the percentage loss from this cause.

(b) Mischievous Stone Throwing and Rifle Shooting:—Figure 18 shows the dry flashover on units *G* and *H*, and Table III gives the flashover voltages of broken units in percent of the unit when unbroken. Figure 19 shows the wet flashover on units *J* and *I* and Table IV gives comparative flashovers of broken units, as in Table III. Figs. 22, 23 and 24 show the flashovers on units having broken sheds.

FIG. 21—THE SURFACES OF THE NEW DESIGN DO NOT READILY COLLECT DUST

FIG. 22—60 CYCLE DRY FLASH OVER TESTS WITH SECOND SHELL BROKEN

FIG. 23—60 CYCLE WET FLASH OVER TESTS WITH SECOND SHELL BROKEN

As would be expected from a study of the dielectric field diagrams, the breaking of the second shed of the proposed type of design has practically no effect upon the flashover values of the insulator. In fact, as shown in the illustrations, the paths of the dry and wet flashovers did not follow over the broken shed. When sheds are broken, the corona formation and static streamers build out over the surface of the older type of design at a lower voltage than when the units are intact. The paths of flashover over these older types, therefore, follow the surface of the insulator. In the proposed type of design the absence of streamers from the porcelain surface causes the arc to keep clear of the insulator. A power arc will, therefore, be less liable to cause complete failure of a broken unit of the proposed design.

TABLE III—KILOVOLTS FLASHOVER

Sheds Broken	Top		Second		Second and Third	
Illustrated in Fig.			22	23	24	
Dry or wet	dry	wet	dry	wet	dry	wet
Insulator *G*	85	80	100	100	68	74
Insulator *H*	79	77	82	97	54	70

TABLE IV—KILOVOLTS FLASHOVER

Sheds Broken	Top	Top and Third	All sheds	
Dry or wet ..	dry	dry	dry	wet
Insulator *J* ..	87	78	59	30
Insulator *I* ..	85	70	34	15

One of the most important features of the proposed design is that when the units are hit by stones, etc., the rain sheds will not crack or break beyond line *a* Fig. 6, due to the shape of the individual parts. The rain sheds of the older types of designs when hit are very likely to crack or break up into the cemented section. The first voltage surge or even normal line voltage will, therefore, often puncture the re-

*"Ceramics in Relation to the Durability of Porcelain Suspension Insulators," *Trans. A.I.E.E.*, Vol. XXXV, 1916.

maining shells. In fact, in the two series of tests photographed, both the older type of units punctured during the dry arcover after the sheds were broken.

One each of units *H, I* and *K* and two of *J* were subjected to rifle shots. Twenty-two caliber long bullets were shot at the insulators from about 30 yards distance and in a line at 45 degrees to their axes. Figs. 25, 26 and 27 show the comparative breakage and the ability of the broken units to thereafter withstand electrical test. The shooting was done by men disinterested in the design of the insulators who were requested to do as much damage as possible.

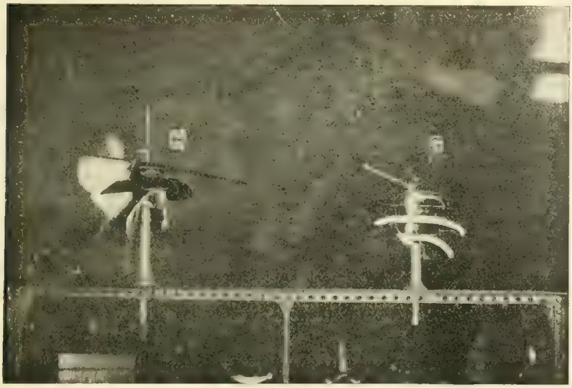


FIG. 24—60 CYCLE DRY FLASH OVER TESTS WITH SECOND AND THIRD SHELLS BROKEN

FIG. 25—EFFECT OF 15 RIFLE SHOTS

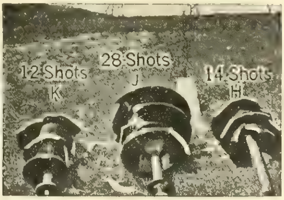


FIG. 26—EFFECT OF RIFLE SHOTS

FIG. 27—60 CYCLE DRY FLASH OVER TESTS AFTER BREAKAGE FROM RIFLE SHOTS

Fig. 25 shows insulators *I* and *J* after 15 shots were fired at each. The top, second and third shells of *I* were broken, the second shell being cracked into the cemented section. The second shell of *J* was chipped in two places, the rest of the insulator being intact. Fig. 26 shows insulators, *H, K* and *J* after 14 shots were fired at *H*, 12 at *K* and 28 at *J*. The second and center shells of *H* were cracked and the center of *K*. The sheds of *J* were chipped off in a few places but the shells were not cracked. These five units were then set with their axes at right angles to the line of fire. Not more than 5 or 10 shots were necessary to strip the main part of the remaining sheds from insulators *H, K* and *I* while one unit of type *J* still retained a considerable portion of its sheds after approximately 100 shots had been fired at it. The sheds remaining on the two units *J* were then knocked off by a hammer, to illustrate to those present that the surface of the insulator that follows flow line *a* would not be cracked thereby.

Fig. 27 shows the first dry flashover test made on these units after the shooting. Units *H, K* and *I* punctured at 33, 43 and 56 kilovolts, respectively. Unit *J* of the proposed type of design flashed over at a 105 kilovolts, the remaining porcelain body bounded by line *a* still being intact.

(c) Insufficient Strength as a Support: Two samples as per Fig. 28, were tested to determine the resistance to side pull. In each case load was applied at the wire groove which was one foot from the base of the pin. The parts from which insulator *L* was formed were obtained by trimming off the rain sheds of individual shells of unit *J* before burning and the mechanical test should, therefore, be about the same as that of unit *J*. The pin of unit *L* was cemented directly into the insulator. A separable pressed steel thimble was cemented into insulator *F*. The one-inch bolt of the pin cemented into insulator *L* failed at 4400 ft-lb., and 3100 ft-lb. bent the pin of insulator *F* as shown, the position of the insulator being such that additional load could not be applied. Both units were electrically intact after these tests.

(d) Brittle Material: All units used in these comparative tests were made of the same porcelain body and hence the question of brittleness, which is a ceramic problem, does not enter.

5—Lightning—It is generally conceded that a direct stroke of lightning will destroy any insulator that comes within its wake. However, some of the older designs, especially those having deep inner shells and heads of

large diameter, were very vulnerable to any sudden impact voltage. In the first place, the impulse ratio (flashover voltage at high frequency divided by flashover voltage at normal frequency) of such insulators is rather high, and in the second place the ratio between flashover voltage in air and puncture voltage under oil is comparatively low. Furthermore, the body of the porcelain bounded by the flow lines *a* should have an impulse ratio close to one. A very high impulse voltage might, therefore, puncture through the rain sheds of the insulator, leaving this body of the unit intact. The thicker section of porcelain between line and pin will also materially increase the factor of safety of the unit.

FIG. 28—RESISTANCE TO SIDE PULL

6—Unequal Expansion of Metal, Cement and Porcelain—The introduction of a resilient material between the tops of shells should eliminate the tendency of certain older designs to split off. Greater radii of curvature at the tops of the insulator shells and a cement section sloped from the axis should tend to eliminate the trouble from any difference of coefficient of expansion of the porcelain and cement.

7—Internal Stresses in the Material—Internal stresses set up in the insulator parts during manufacture should be very much decreased by the elimination of small radii in corners and sudden changes of cross section of the material.

CONCLUSIONS

Briefly stated, it is believed that the advantages of the proposed type, Fig. 6, over the older commercial types in resisting failure in service would be as follows:

1—When the insulator is dry, the corona and static formations are practically limited to the tie wire and line wire, up to flashover voltage.

2—When the insulator is wet, no corona or static formation occurs up to the flashover voltage. The flashover voltages for given overall dimensions are thereby increased.

3—The leakage resistance per shell is increased gradually from the head to the center shell. This takes into account the probability of the lower sheds becoming dirtier than the tops. The voltage distribution per shell is, therefore, equal when the insulator becomes dirty and wet and a heavy leakage current passes over the insulator.

4—Since the capacity per shell is about equal, the voltage distribution per shell will be equal when the insulator is clean and in dry air.

5—Since the distribution of voltage per shell depends upon the capacity current and leakage current, the distribution of voltage per shell in these designs should be approximately equal under all operating conditions.

6—The resistance of the insulator to side pull for a given weight and given electrical strength is relatively high. This is due to the feature of the design whereby the flow line *a* of the electrostatic field and the mechanical stress lines coincide.

7—The design of the individual shells is such that when they are tested before assembly the surface conforms to the electrostatic flow lines *a*. This allows testing of the individual parts to a higher percentage of service voltage than was possible with the individual shells of older designs.

8—Due to the shape of individual parts and of the assembled unit, the insulator sheds when hit by stones, rifle, balls, etc., do not break beyond the surface *a*. The unit, therefore, offers a considerable percentage of its original resistance to flashover after the sheds are broken. The same feature tends to protect the insulator from complete failure during flashover in service.

9—Each characteristic of the insulator which would vitally affect durability in service has been treated uniformly throughout the line.

Manufacture of Six Inch High Explosive Shells

For the United States Army

T. D. Lynch
Research Engineer,
Westinghouse Electric & Mfg. Co.

THE Pittsburgh District has quietly done its share in winning the war by furnishing large quantities of shells, together with the many other supplies needed by the United States and Allied forces. In order to accomplish these results it has been necessary to utilize every available facility and make use of existing buildings with and without extensions, to rearrange standard machines and supplement with special equipment, to reduce standard materials to the form and quality needed and to make use of the labor available, both skilled and unskilled. The extent of this work is indicated by the fact that a single firm (The Westinghouse Electric & Mfg. Company) has shipped 10 000 to 15 000 finished shells, weighing 1 000 000 to 1 300 000 pounds, daily during a period of many weeks and yet this is but one of the many organizations carrying on this and similar war work in and about Pittsburgh. These shells were manufactured at five different plants of the Company and were for both the British and the United States Government.

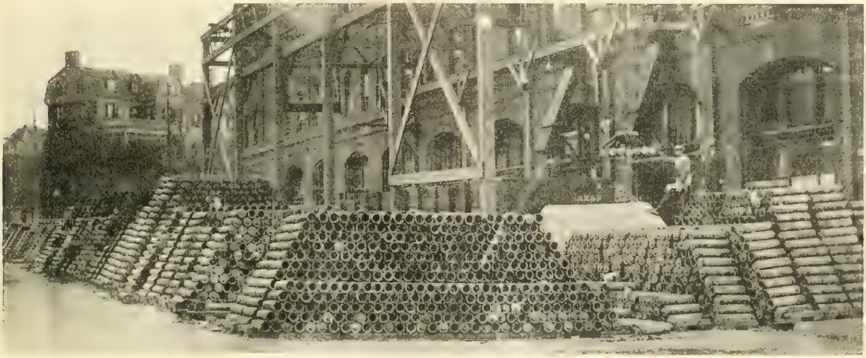


FIG. 1—A GENERAL VIEW OF SHADYSIDE PLANT
Showing the yard storage and crane handling device with seven shells suspended on lifting fork.

The following is a description of the Shadyside Plant of the Company, which was equipped to manufacture six inch shells at the rate of 3000 per day, working day and night. The Company had laid out and equipped four other shell manufacturing plants when the problem was presented of changing over the Shadyside plant from the manufacture of automobile equipment to that of shells. Thus there was ample opportunity to lay out the routing of the shells through the plant so as to require the minimum amount of handling. The shells

FIG. 2—SIDE VIEW OF SHELLS IN DIFFERENT STAGES OF MANUFACTURE
From the left to right: rough forging; rough turned; nose swedged; bored and faced; finish turned; band groove cut and waved; band swedged; band turned; finished shell.

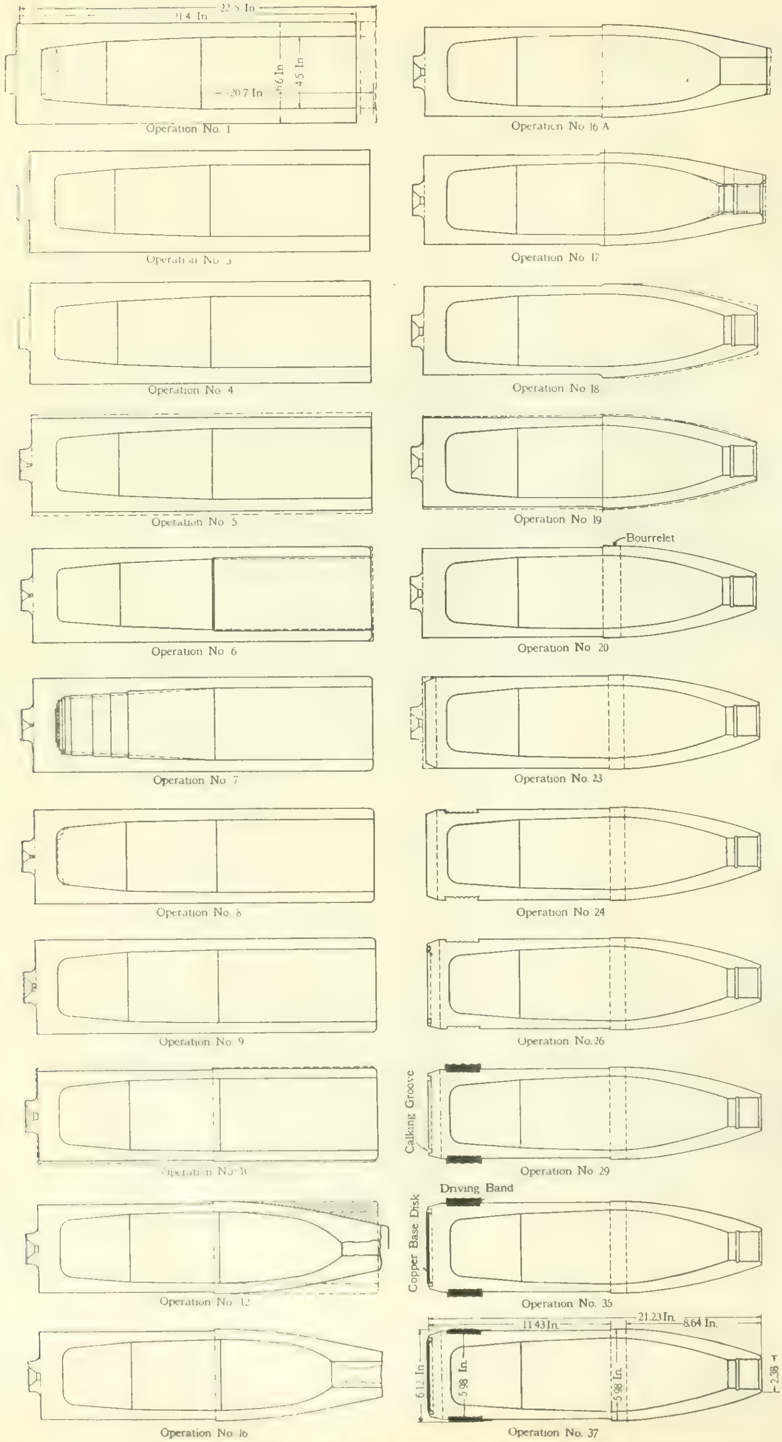


FIG. 3—CHART SHOWING CHANGES IN THE SHAPE OF THE SHELL AT THE SUCCESSIVE OPERATIONS

Oper. 1—Layout to cut off open end.

Oper. 2—Cut off open end.

Oper. 3—Face base end.

Oper. 4—Center base end.

Oper. 5—Rough turn body.

Oper. 6—First bore and face open end.

Oper. 7—Second bore.

Oper. 8—Finish bore.

Oper. 9—Re-center.

Oper. 10—Turn for concentricity and true up base end.

Oper. 12—Swedge nose end.

Oper. 13—Heat and quench in oil.

Oper. 14—Draw temper.

Oper. 16—Rough drill nose end.

Oper. 16A—Rough face nose end.

Oper. 17—Bore, chamfer, face, undercut, ream, cut inside radius and tap nose end.

Oper. 18—Rough turn nose.

Oper. 19—Finish turn nose and body.

Oper. 20—Grind bourrelet.

Oper. 23—Remove boss face for weight and cut bevel.

Oper. 24—Cut band groove and wave.

Oper. 26—Cut calking groove.

Oper. 29—Swedge in copper band.

Oper. 30—Wash with alkali.

Oper. 31—Wash with water.

Oper. 32—Clean with shot blast.

Oper. 33—Varnish inside of shell.

Oper. 34—Stamp shipping serial number on shell.

Oper. 35—Fit in copper base disk.

Oper. 37—Finish copper band.

are moved from one machine to another and from floor to floor on double roller conveyors and continuously-operated elevators. The shells come to the workmen on the upper conveyors and, after completing each operation, the workmen place them on the lower conveyors

FIG. 4—CENTERING OPERATION

A jig is mounted on trunnions which are firmly attached to a drill press. The shell is received over the roller conveyors at the left and pushed over the mandrel in the jig, which in turn is quickly revolved about its trunnions into the position shown.

and send them on to the next operation. As a result the machines are fed from a continuous supply so that no space is wasted in storage between operations, thus permitting a compact arrangement of machines.

FORGINGS

The shell forgings are furnished by the United States Government and are produced from steel made on specifications calling for carbon 0.45 to 0.63 percent,

FIG. 5—ROUGH TURNING OPERATION

The lathe is large and rigid so that heavy cuts can be taken.

manganese 0.50 to 0.90 percent, phosphorous not over 0.06 percent, sulphur not over 0.06 percent, and silicon 0.10 to 0.35 percent. This composition gives a steel that lends itself readily to heat treatment. The steel is made in the open hearth furnace, cast into ingots and rolled into round cornered billets. These billets are notched on the side at proper intervals with a saw or acetylene torch. They are then placed under a hammer or quick acting press and broken into slugs of proper weight to make a single shell. These slugs are piled with both ends exposed and careful inspection is made of the fresh fractured surfaces. All slugs showing signs of

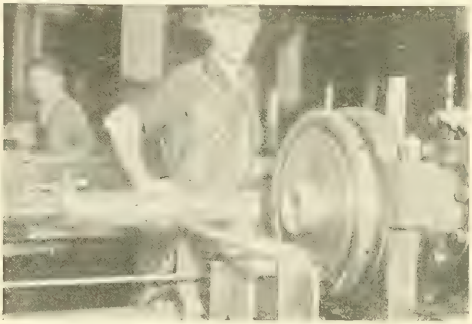


FIG. 6—BORING OPERATION

The shell is held in the lathe head by a quick acting mechanical chuck. The rigid boring bar carries a form tool with four cutting edges, each cutting edge being notched as shown.

piping or undue segregation, as indicated by flaws or discoloration, are discarded and only the perfect slugs are used in the manufacture of shells.

The slugs are then heated in a continuous furnace to a forging heat of 1000 to 1100 degrees C. (1830 to 2000 degrees F.) and removed from the furnace to a press where they are placed in a pot die, upset and pierced, forcing the material to flow up and around the piercer plunger, yet confining it within the pot die, resulting in the rough forging as furnished the machiner. In some forge shops, the rough forging is passed through a draw bench to bring it to a more uniform size.

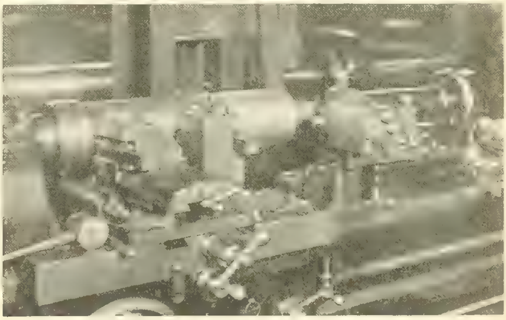


FIG. 7 TURNING FOR CONCENTRICITY

Three cutting tools are used. The two turning tools are fed automatically while the facing tool is fed by hand.

The slugs must be heated uniformly and the presses kept in perfect alignment in order to produce a concentric shell forging. After final forming at the press or draw bench they should be cooled uniformly and slowly with the object in view of making them readily machin-

able. Annealing or pit cooling after forging gives most satisfactory machining qualities. A code, indicating the manufacturer, as well as the heat of steel from which the forgings are made, is maintained on each piece of steel and on the finished shell, so that a complete history of each shell is known.

FIG. 8—NOSING FURNACES

The furnaces are provided with cast-iron water-cooled fronts, having holes for six shells in each unit. A shell with end heated is shown on the roller conveyor in the foreground, on the way to the nosing press. The furnaces are fed by movable conveyors which in turn get their supply from stationary conveyors on which the shells come in from the rear of the furnaces.

The forgings are received on flat cars and unloaded with a crane. A specially designed lifting fork is used, having seven prongs, each of which extends into a shell

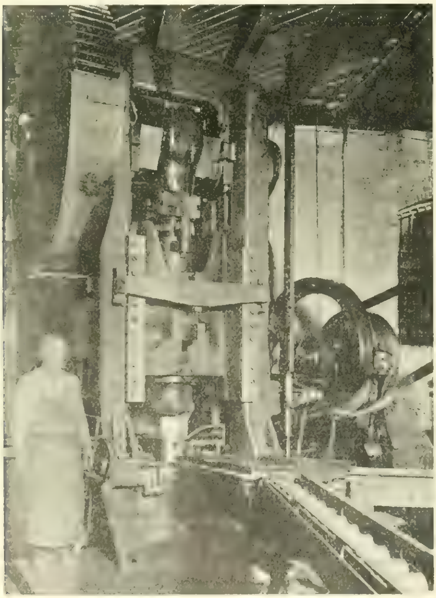


FIG. 9—NOSING-IN PRESS

Shells, with the open end heated come on the movable conveyors directly from the surrounding furnaces, are placed in the power press as shown and nosed in.

as shown in Fig. 1. The forgings are stored in the yard or are placed on roller conveyors which take them by gravity to the storage space in the basement, where they are piled by heats in classes I, II, or III, depending upon the hardening numeral. The hardening numeral is the sum of three times the carbon, plus the

FIG. 10—ONE OF THE HEAT-TREATING FURNACES

The shells are rolled through the furnace in double rows, the nose ends being towards the middle of the furnace. Double doors are arranged at each end to provide the least possible opening when shells are put in or taken from furnace. The conveyor at the right leads to the corresponding quenching tank.

manganese content. Thus,—

	Carbon	Hardening Numeral
Class I	0.45 to 0.51	2.05 to 2.30
Class II	0.52 to 0.58	2.22 to 2.47
Class III	0.57 to 0.63	2.40 to 2.65

The shell forgings are coded and passed through the consecutive operations in separate classes so far as

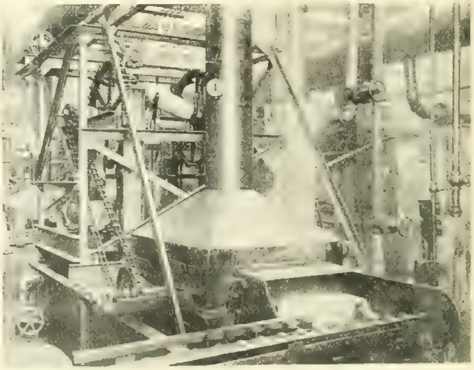


FIG. 11—QUENCHING TANKS

The roller conveyor in the foreground delivers each shell into the position shown at the ingoing end of the tank. It is then lowered automatically into the quenching oil. The hood collects the fumes from the quenching oil. An elevator removes the shell automatically from the other side of the tank and drains it as shown near the top of the elevator.

possible, the heat code, indicating the class, being kept on the forging during all subsequent operations.

At the Shadyside plant forty-three distinct opera-

tions are involved in converting a shell forging into a completed six inch shell ready to receive the charge of T.N.T. or other high explosive and the fuse mechanism. Beginning with the forgings as received on cars and concluding with the finished shell as loaded on cars ready for transit to the loading plant, the following is a brief description of the operations.

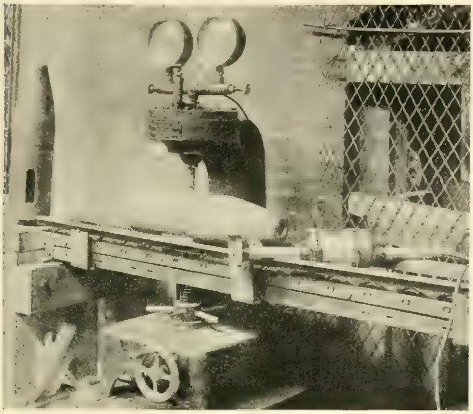


FIG. 12—BRINELL TESTING OUTFIT

The shells are brought to the Brinell testing machine on a conveyor. A small flat spot about one-half inch square is ground by a hand grinder shown at the right to which the test is applied. Tensile test specimens were taken from opposite sides of the shell shown at left.

MACHINING

The shell forging as it comes from the storage pile is laid out by means of a U-shaped gauge, using the inside of the base as a reference point and prick-punching the positions on the two ends of the shell where they are to be cut off. (Operation 1, Fig. 3). The open end of the shell is cut off with a parting tool, (Oper. 2), the shell being held in a lathe by means of a split chuck. The base end is then faced, (Oper. 3), the shell being held in a lathe by means of a three point chuck. Immediately following this operation an inspector gages the length to see that it is correct. The centering of the base end, (Oper. 4), is shown in Fig. 4. The shell is placed over an expanding mandrel and lined up from the rough bore while the center is drilled in the base. This is followed by transferring the code number from the side to the base end. The body of the shell is then rough turned, the shell being mounted in a lathe, supported on the center at the base end and on a three point contact mandrel at the open end. This operation is shown in Fig. 5. The outside diameter is then checked for size.

BORING

The boring of the shell is divided into three operations, (6, 7, and 8). The shell is first rough bored to about its middle and the open end faced off. The diameter of bore and length of shell are checked. The rough boring is then continued to the bottom of the shell using a specially formed tool with four cutting edges which are notched in order to break up the chips, as shown in Fig. 6. In these boring operations a cutting compound is used as a lubricant on the cutting tool. The shell is held in the lathe by a quick-acting mechanical chuck, clamping it from the outside. The finishing cut is made with a special tool, so formed as to give the proper shape to the inside of the shell. This operation is followed by inspection of the bore for accuracy and smoothness.

FIG. 13—FINAL TURNING

The tool at the right is finish turning a straight portion of the shell. The tool at the left is finish turning the nose end of the shell, the curvation being produced automatically.

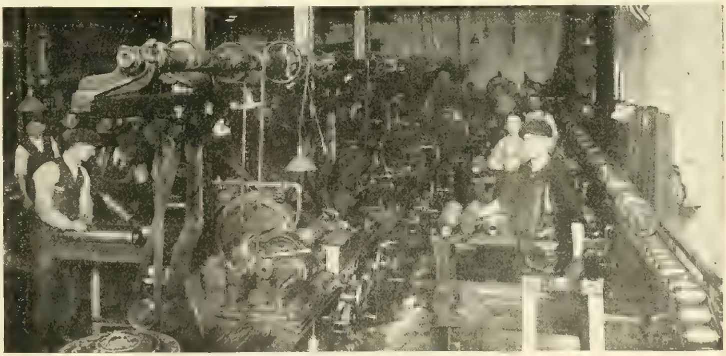


FIG. 14—GRINDING MACHINES

A battery of grinding machines where the bourrelet is ground accurately to size.

TURNING FOR CONCENTRICITY

The base of the shell is now re-centered. (Oper. 9). The first centering, (Oper. 4), was done with reference to the rough bore but the re-centering is done from the finished bore and must be very accurate since the following operation depends on the new center for

uniformity in thickness of shell wall. The shell is mounted on a mandrel with a double set of air-operated three-point contacts, one set at the base and the other at the open end of the shell. After recentering, the shell is turned for concentricity and the base is faced. (Oper. 10). The shell is supported on the center at the

FIG. 15—WEIGHING SHELLS

The shells are rolled across the scale bed and weighed accurately. The three inspection tools shown in the foreground are for the purpose of locating and marking the position for cutting off the base of shell, checking the thickness of the base and the overall length of the shell.

base end and on a three point contact mandrel at the open end. As shown in Fig. 7, three tools cut at the same time, the first beginning at the base and turning up to the middle, the second for slightly larger diameter beginning at the middle and turning up to the open end, and the third facing the base. It is important to have the shell wall accurate in thickness and truly concentric in order that the shell may have the balance so necessary in flight. The shell is now ready for the first pre-

FIG. 16—CUTTING AND WAVING THE BAND GROOVE

The tool on the left side of the shell turns the band groove while the one on the right does the waving. An eccentric causes the waving tool to oscillate in the sliding head shown at the right. This tool oscillates six times for each revolution of the shell.

liminary inspection by the Government, when a careful examination is made for contour and smoothness of bore, thickness of base, and thickness of shell wall.

SWEDGING AND HEAT TREATING

The open end of the shell is heated for a distance of approximately 5¾ inches in a furnace so arranged that the open end of shell extends through a cast iron, water cooled front into the furnace, as shown in Fig. 8. The shell is turned over at intervals to give a uni-

FIG. 17—HYDRAULIC TEST

The shell is filled with a cutting compound, from the pipe shown at the left, placed in the hydraulic press shown at the right, the press head is brought down on the nose of the shell, a copper washer serving as a seal. A small plunger passes through the press head into the shell and thus produces the desired internal pressure. This pressure is indicated on a gage attached to the head of the press and connecting directly with the inside of the shell.

form heat. The shell, when at the proper heat is removed from the furnace and conveyed to the power press, Fig. 9, where it is placed in a vertical position and the press closes in the open end, forming the shell nose of proper shape in a carefully made die. (Oper. 12). The shells are handled into and out of the fur-

FIG. 18—PRESSING ON COPPER BANDS

The copper band is heated in the furnace in the background and then slipped over the shell in the hydraulic press to the position of the band groove, when the press is actuated and the band pressed firmly into position.

nace on roller conveyors, with one end hinged near the press and the other end mounted on a circular track in front of the furnaces, one conveyor taking care of the output of two furnaces.

From the swedging press the shells go to the heat treating furnace where they are heated to 830 degrees C.

and quenched in oil. (Oper. 13). The outgoing end of one of these furnaces is shown in Fig. 10, where two rows of shells may be seen in the furnace and one shell on the roller conveyor which leads to the quenching tank.

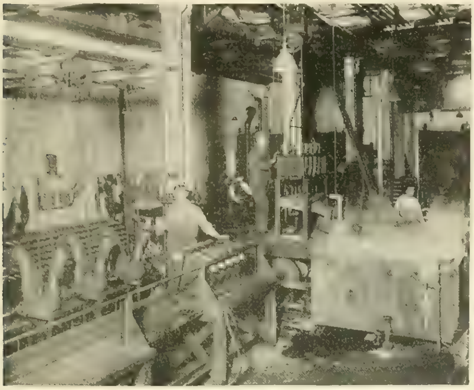


FIG. 19—CLEANING

The triple wash of a hot solution of lye, hot water and steam is applied to the inside of the shell by means of the apparatus shown at the right. The shells are then placed in the shot blast machines shown at the left. The shells are held in an inclined position and rotated while a shot blast is applied to the inside.

These furnaces are of the continuous type and of proper size to hold 84 shells each at one time, 42 in each row. The bottom of the furnace is inclined from the ingoing to the outgoing end to facilitate the rolling of the shells. The furnace is fitted with burners which burn either oil or gas. Pyrometers are used for observing the temperature in the furnace, with one fire end located about six feet from one end of the furnace and another

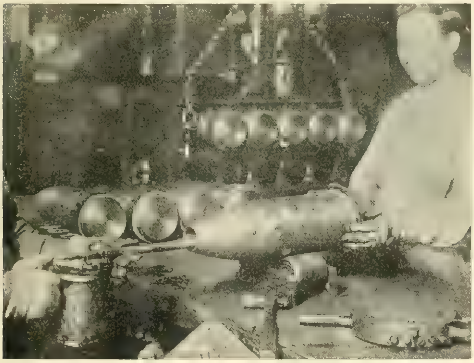


FIG. 20—VARNISHING INSIDE OF SHELLS

The shell is placed on two rollers and rotated rapidly by hand while the varnish sprayer is moved slowly the length of the inside of the shell and back. After which the numbering dies, shown at the right, are clamped on the shell and each struck in succession by the hammer.

similarly located on the opposite side at the other end, both connected to an indicating instrument for the use of the operator of the furnace. A third fire-end is also placed about 6 feet from the outgoing end of the furnace and is connected to a recording instrument which gives a continuous record of the furnace temperature. Each furnace has an output of 60 to 65 shells per hour. After being properly heated the shells go to the quenching tanks. A general view of a row of quenching tanks is given in Fig. 11. Each shell coming on the conveyor from the furnace, is received by arms which lower it and place it on the edges of two horizontal bars extending lengthwise and near the bottom of the tank. A projection on an endless chain, rolls the shells through the oil at a depth of about 18 inches from the top of the shells to the surface of the oil. This conveyor delivers the shells to an elevator which, in turn, removes them from the oil. The supports on the elevator are so arranged as to incline the shells sufficiently to permit the oil to drain freely. This elevator, in turn, places the shells on the roller conveyor for transit to the drawing furnaces, where they are again heated to approximately 675 degrees C. (Oper. 14), the exact temperature varying with the class of steel, the higher carbon steel

FIG. 21—TURNING COPPER BAND

The copper band is turned by a tool on the opposite side from that shown and afterwards shaped and grooved by two additional tools shown in the foreground.

requiring a higher temperature than the low carbon steel. The shells are kept in this furnace for a period of about one hour and twenty minutes, after which they are removed, piled in lots and allowed to cool slowly. Each pile of approximately 700 shells constitutes a testing lot.

These quenching and drawing operations are carried on to put the grain of the steel in the best possible condition and to give a proper elastic limit to insure no distorting or upsetting action when the shell is fired from the gun. The steel should retain other physical properties necessary for the shell to fragment satisfactorily when explosion occurs after it is fired from a gun.

TESTING

Hardness tests are made with a Brinell testing machine on five percent of the shells in each testing lot. From these Brinelled shells the Government inspector selects two shells for physical tests. Physical tests are made on two test specimens, one from near the base

and the other diametrically opposite near the middle, both of which must show a tensile strength of not less than 90 000 pounds per square inch, true elastic limit of not less than 45 000 pounds per square inch, and elongation of not less than 15 percent in two inches. Fig. 12 shows a shell in the Brinell testing machine.

FIG. 22—FINISHING OPERATION

This shows a portion of the Government inspection room where final inspection is made by the Government. The outside of the shell is painted, as shown in the foreground, by rolling the shell over a pad saturated with the finishing varnish. The shipping plug is put in the nose of the shell and grommets placed over the band as shown

FINAL MACHINING

The nose of the shell is rough bored and faced in a drill press, (Oper. 16 and 16-A), followed by boring, chamfering, facing, undercutting, reaming, cutting inside radius and tapping. (Oper. 17). The nose end of the shell is rough turned (Oper. 18) and the nose and body finish turned (Oper. 19), Fig. 13, while the shell is supported between the center in the base and a plug screwed into the nose of the shell. This plug, as shown in Fig. 2, has the shape of the frustrum of a cone on the outboard end which fits into a recess in the lathe head, holding the shell firmly in position while being turned. Following these operations the code number is transferred from the base to the body of the shell.

The grinding of the bourrelet (Oper. 20) is shown in Fig. 14.

Fig. 15 shows the weighing of the shell (Oper. 21) to determine how much material must be removed from the base to bring the shell to the proper weight. The point at which the base is to be cut off is marked by the use of a micrometer tool and another mark made exactly one inch further up so that the accuracy of the cut off may be checked later. After this the inside of the nose is gauged for concentricity by the use of a deflectometer, (Oper. 22). This instrument is attached to a plug which is screwed into the nose of the shell. The shell is rolled over and the instrument indicates the amount the nose is out of true. After passing this inspection the boss on the base is removed (Oper. 23), the shell is faced for weight, and the bevel cut on the base end.

The operation (24) of cutting the band groove and waving is shown in Fig. 16. This is done on a lathe by a tool which cuts the groove to its proper depth, leaving five raised projections completely around the shell in the bottom of the cut. Two side tools are arranged to operate in such a manner as to undercut the sides of the groove into dovetail shape. A fourth tool, located on the opposite side of the shell, is mounted on a sliding head which oscilates horizontally six times per revolution of the shell, so as to cut first one side and then the other of the raised rings in such a manner as to leave five waved rings around the entire circumference of the shell in the bottom of the groove. The copper band which is placed in the band groove serves as a gas check and engages the rifling of the gun, causing the shell to rotate. The gyroscopic effect thus produced keeps the shell straight in its flight. The waving in the bottom of the groove prevents the band from turning on the shell.

After an inspection of the band groove and base the calking groove is cut in the base end of the shell (Oper. 26). This is done by two cutters maintained in such a way as to leave a dovetailed circular slot at the base suitable for calking the lead-lined copper disc in position. This disc is used to guard against any possible leakage of hot gases from the driving charge through an undiscovered piping or other flaw in the base of the shell which might result in a premature explosion. This operation is followed by the second preliminary inspection by the Government, when all dimensions including concentricity of nose and uniformity of wall thickness are carefully checked.

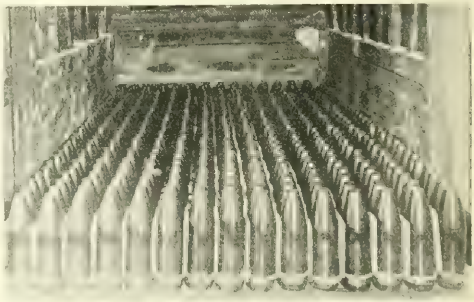


FIG. 23—METHOD OF LOADING SHELLS IN BOX CAR

Strips of wood (not shown) are placed across the car between each row of shells to brace them longitudinally.

HYDRAULIC TEST

The hydraulic test is shown in Fig. 17. A gauge

is mounted on the head of the press, on the opposite side from that shown, which is connected by an opening through the nose of the shell and indicates the actual pressure applied. After sustaining a pressure of 10 000 pounds per square inch for 15 seconds the shell must not show an expansion of more than 0.006 inch and must be free from any leakage.

Fig. 18 illustrates the swedging of copper bands. (Oper. 29). This operation consists in heating the copper band to about 760 degrees C., placing it over the shell at the band groove, and shrinking it into position by means of a hydraulic press which forces the metal to flow into all parts of the groove.

CLEANING THE SHELLS

The shells are now washed first with an alkali solution and then with water (Oper. 30 and 31). The shells are handled in racks, holding ten shells each, by overhead cranes. These loaded racks are placed in frames as shown in the middle of Fig. 19. A small pipe extends into each shell and a hot alkali wash is pumped into the shells, followed by a hot water wash and finally by a steam bath. The inside of the shell is further cleaned by a shot blast (Oper. 32) to remove any rust or foreign matter that may cling to the surface during the washing operation. The shell is placed in an inclined position on one of the shot blast machines and rotated while the blast is blown against the bottom of the shell in such a manner as to thoroughly clean the entire inside. Finally, an air blast is applied to complete the cleaning operation.

After cleaning, the inside of the shell is varnished as shown in Fig. 20 (Oper. 33). The shell is rotated as shown while the inside is sprayed with a clear varnish, thus forming a thin protective coating over the entire inside surface. Following this, the shipping serial is stamped on the shell (Oper. 34) and, after an inspection of the interior by the use of a small electric lamp, it is sent on to the lathes where the lead and copper disc are fitted on the base and calked in position (Oper. 35). A movable tool, placed on the tail stock of the lathe, is moved up against the base of the shell, holding the copper and lead discs tightly in position while a small wheel is so arranged as to spin the edge of the copper disc into the inner dovetail of the groove. This is followed by filling the remainder of the groove with a strip of lead and pressing it into position with a second small wheel which fills the outer dovetail of the calking groove.

The copper band is turned to proper size (Oper. 37) as shown in Fig. 21. Then the threads in the nose of the shell are accurately sized with a hand tap, and a complete inspection is made by the manufacturer, including weighing and checking all parts for dimensions.

The shells are then delivered to the bond room, where final government inspection is made. After passing final inspection a blue priming coat is applied to the outside of the shell which protects it from rust in transit and gives a good priming foundation for the coat of paint which is given to the shell after it has been filled. This coat is applied, as shown in Fig. 22, by rolling the shell over a heavy felt pad which is saturated with the priming material. A transit plug is then put in the nose end of the shell and a grommet placed over the copper band for protection in transit, thus completing the manufacturing operations. The shells are then loaded in box cars as shown in Fig. 23 and shipped to the filling plant.

Resistance and Reactance of Commercial Steel Conductors

H. B. Dwight

IRON and steel wires and cables are being used to an increasing extent as conductors for branch power lines where the currents to be carried are not large. This is partly due to the high cost of metals, making it necessary that advantage be taken of every possible economy in design, and prohibiting the use of a copper or aluminum conductor when a cheaper steel conductor can do the work. The utilization of steel conductors is also partly due to the increased knowledge of their electrical properties, so that they may be applied to a projected line with more confidence that the results expected will be obtained. Steel conductors are now being used of larger diameter than formerly, and there is need for a knowledge of their properties. There is also a possibility that steel cables or cables with large steel cores will soon be needed for very high voltage lines, where corona loss is troublesome.

Although galvanized steel conductors have not given rise to mechanical troubles to any extent on the lines where they have been used, but have indeed in many ways increased the factor of safety, the question has sometimes been raised whether they do not impose a greater hazard than copper cables due to the possibility of their rusting through and breaking. While it is obvious that steel conductors have a shorter life than copper ones, still the use of the former is known to be reasonably safe, from many years of practical experience, for the use of steel cables as power conductors is exactly the same from this point of view as their use as ground conductors, in which way they are used on practically every transmission line.

As is well known, the resistance and reactance of iron and steel wires and cables vary considerably with the grade of the metal and with the number of amperes of current which is being carried. These properties are best determined by separate tests for each type and size of wire and cable. There does not seem to be any successful method of predetermining the properties of

one conductor from the tests of another size of conductor. A certain number of tests have been published but the results are not very complete and do not agree very closely with each other, and so are not very useful for design purposes. A complete and consistent set of test curves is much needed by transmission engineers. In the absence of such tests, the writer has drawn up the approximate curves in Fig. 1 to 15, based on the average results of the tests so far published.

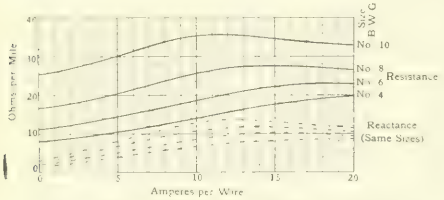


FIG. 1—ORDINARY STEEL GRADE WIRES, 60 CYCLES

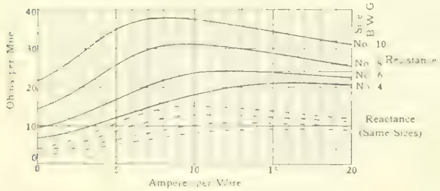


FIG. 2—GRADE BB WIRES, 60 CYCLES

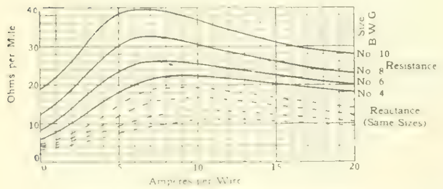


FIG. 3—GRADE EBB WIRES, 60 CYCLES

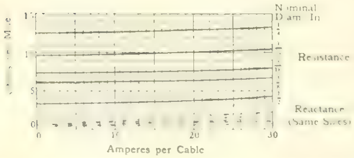


FIG. 4—SIEMENS-MARTIN SEVEN STRAND CABLES, 60 CYCLES

The tests of a given type of steel conductor show two main kinds of variations when different samples are tested. First, there are variations in the conductivity for direct current, which is the same as the conductivity for a very small alternating current, and second, there are variations in the percentage increase in resistance when alternating current is carried.

In order to make the set of curves consistent as regards direct-current conductivity, the following values, expressed as percentages of the annealed copper standard, have been assumed:

Grade EBB (Extra Best Best)	16 percent
Grade BB (Best Best)	14 percent
Ordinary Steel Grade	12 percent
Siemens-Martin	9 percent
High Strength	8 percent

The percentage increase of resistance of a given size of wire or cable at a given strength of alternating current is greatest for Grade EBB and least for High Strength Steel. The other grades have intermediate values in the order given in the above list. It therefore results that a medium grade of steel may have a lower

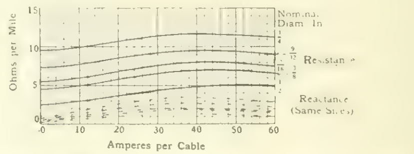


FIG. 5—ORDINARY STEEL GRADE SEVEN STRAND CABLES, 60 CYCLES

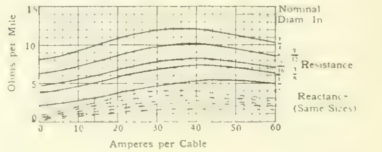


FIG. 6—GRADE BB SEVEN STRAND CABLES, 60 CYCLES

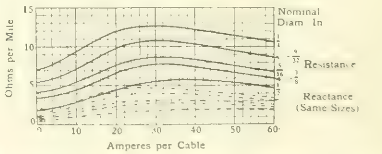


FIG. 7—GRADE EBB SEVEN STRAND CABLES, 60 CYCLES

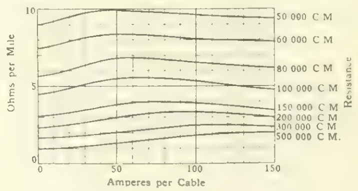


FIG. 8—ORDINARY STEEL NINETEEN STRAND CABLES, 60 CYCLES

resistance for its load of alternating current than a grade nearer the top of the above list, which is based upon direct-current tests. The percentage increase in resistance is practically proportional to the frequency at commercial frequencies, and this fact enables curves for 25 and 60 cycles to be compared.

The reactance plotted in the figures is the internal reactance, that is, the reactance due to magnetic flux inside the conductors. In order to obtain the total reactance of the electric power line, the external reactance should be added. This may be taken from tables prepared for use with circuits using copper conductors, but in general, it will be sufficient to add 0.8 ohms per mile for 60 cycles and 0.3 ohms per mile for 25 cycles.

The reactance of steel conductors is practically proportional to the frequency at commercial frequencies.

The conductors referred to in Figs. 1-7 and 9-14 are wires of the Birmingham Wire Gauge (B.W.G.) and cables made up of such wires. There is some discrepancy between the nominal diameters of the cables, and their actual diameters, as is shown by Table I.

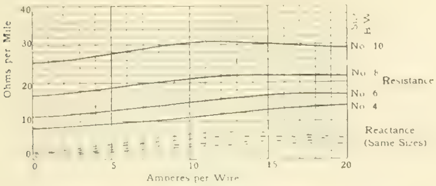


FIG. 9—ORDINARY STEEL GRADE WIRES, 25 CYCLES

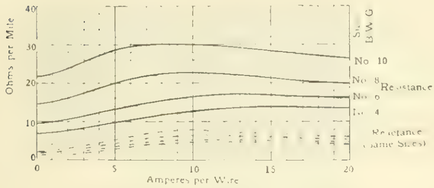


FIG. 10—GRADE BB WIRES, 25 CYCLES

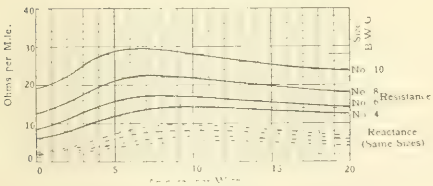


FIG. 11—GRADE EBB WIRES, 25 CYCLES

The Birmingham wire gauge is used largely for telegraph wires of iron and steel. The electrical properties of steel conductors of other gauges can be estimated by

TABLE I—CABLES COMPOSED OF SEVEN STANDARD B. W. G. WIRES

Nominal Diam.	Size of Wires B. W. G.	Diam. of Wires	Actual Diam. of Cable	Sectional Area in Circ. Mils.
¼	No. 14	0.083	0.249	48 200
9/32	No. 13	0.095	0.285	63 200
5/16	No. 12	0.109	0.327	83 200
⅜	No. 11	0.120	0.360	100 800
½	No. 8	0.165	0.495	190 600

changing the values given by Figs. 1-15 in inverse proportion to the change in sectional area of the conductor.

The capacitance of steel conductors is the same as that of copper conductors of the same size, and therefore the usual tables and formulas may be used for determining the capacitance of steel conductors.

The preparation of a set of test curves similar to the curves of this paper would require very inexpensive and easy electrical measurements with standard instruments, if a sample of each conductor about 1000 feet long were available. It would seem therefore that the tests might be made by the manufacturers of the steel, who would be able to obtain the samples most easily.

It is to be hoped that the work of making accurate tests of commercial steel cables will be continued, as

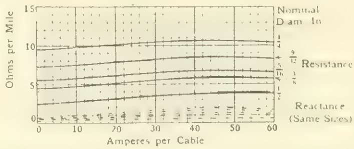


FIG. 12 ORDINARY STEEL GRADE SEVEN STRAND CABLES, 25 CYCLES

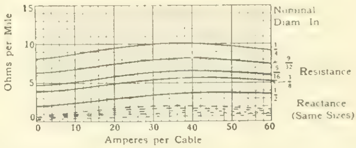


FIG. 13 GRADE BB SEVEN STRAND CABLES, 25 CYCLES

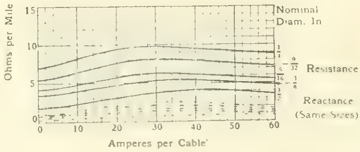


FIG. 14—GRADE EBB SEVEN STRAND CABLES, 25 CYCLES

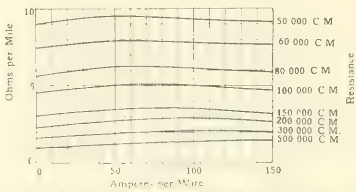


FIG. 15—ORDINARY STEEL NINETEEN STRAND CABLES, 25 CYCLES

the results would be of considerable value to the designers of transmission lines.

The tests on which the curves in this article have been based, were described in the following articles:—

"Effective Resistance and Inductance of Iron and Bimetallic Wires" by John M. Miller, *Scientific Paper No. 252* of the Bureau of Standards, Aug., 1915.

"Iron Wire for Distribution and Transmission Lines," *Electrical World*, April 8, 1916.

"Iron and Steel Wire for Transmission Conductors," by T. A. Worcester, *General Electric Review*, June 1916, p. 488.

"Steel Conductors for Transmission Lines," by H. B. Dwight, Trans. *A. I. E. E.*, Sept. 18, 1916, p. 1237.

"Characteristics of Iron and Steel Conductors," by C. E. Oakes and W. Eckley, *Electrical World*, Oct. 14, 1916.

"Characteristics of Iron Wire for Transmission Purposes," by L. W. Morrow, *Electrical World*, July 14, 1917.

"Iron Wire for Short High-Voltage Lines," by W. T. Ryan, *Electrical Review*, Sept. 22, 1917.

"Iron and Steel Conductors," by R. C. Powell, *Journal of Electricity*, April 1, 1918.

"Characteristics of Iron and Steel Conductors," by C. E. Oakes and P. A. Sahm, *Electrical World*, July 27, 1918.

The Engineering Evolution of Electrical Apparatus—XXXVI

The Development of the Two-Phase, Three-Phase Transformation

CHAS. F. SCOTT

ALTERNATING-CURRENT installations made during the latter eighties were single phase of about 120 to 133 cycles, for lighting circuits only. There were no motors, as the recently invented Tesla rotating or shifting field motor was not suitable for these circuits. Attempts were made to use this principle for the operation of split-phase motors from a single-phase circuit and also to operate polyphase motors at high frequency, but neither of these attempts was successful. Later, when the frequency was reduced and polyphase generators were used, selection had to be made between two-phase and three-phase. Both were produced and there were certain conditions where one was better, while for other conditions the other was preferable.

At that time, when polyphase generators were installed the motor service was usually incidental. The lighting service continued by single-phase circuits and it was simpler to supply such circuits in two groups from a two-phase generator than it was to divide them into the three groups necessitated by the three-phase generator. The interaction between the phases was less and it was simpler to obtain the desired voltage regulation from the generator or from voltage regulators.

Some industrial installations were made for both light and power and in such cases it was usually found that the two-phase system was to be preferred. The long distance transmission circuit with its lesser cost for a three-phase transmission line was scarcely a factor in the central station work, which consisted primarily of single-phase lighting circuits.

The Niagara Falls Power Company, in the first large and pre-eminent alternating-current power plant, employed two-phase generators as it was expected that a large part of the power would be used locally as single-phase for the operation of electric furnaces and electrochemical processes.

Some of the early forms of generator windings and the original form of the polyphase motor designed by Mr. Tesla lent themselves much more readily to a construction for two-phase than for three-phase. The greater simplicity in measuring instruments and in the use of two instead of three transformers for reducing the voltage were also contributing influences in the preference for the two-phase system. In those early years when lighting circuits were being changed from 133 to 60 cycles and the single-phase system was being supplanted by the polyphase system to accommodate induction motors, the inherent regulation of small generators and the kind of regulating and control devices available were very different from present standards. In short, the features of the apparatus and its use for lighting and for incidental power work from central stations and in factory plants gave the preference to two-phase.

One afternoon Mr. L. B. Stillwell came into the Westinghouse Laboratory and said that in a certain negotiation then pending the Company was at a decided commercial disadvantage in proposing a ten mile transmission by a four-wire, two-phase circuit, as a competitor offered three-phase apparatus with a saving in the cost of transmission line of some $10 000. He was considering whether a proposal should be made for supplying the three-phase apparatus. I pointed out some of the manufacturing objections to supplying three-phase equipment when our ordinary products were two-phase, and also recounted the advantages in having a two-phase distributing system. He reiterated, however, that a $10 000 saving in the transmission line was a handicap which would be hard to overcome. It occurred to me that the ideal arrangement would be a three-phase transmission line for supplying two-phase distributing circuits; to which he agreed.

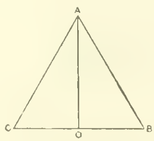


FIG. 1 — ELEMENTARY VECTOR DIAGRAM

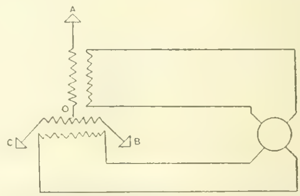


FIG. 2 CONNECTIONS FOR TWO-PHASE, THREE-PHASE TRANSFORMATION

I went to my desk, drew an equilateral triangle, then in a half musing, half mechanical way, without having formulated a definite purpose, drew a line from the upper apex to the middle of the lower side of the triangle. This line made a right angle with the side which it intersected and in an instant my imagination made these two lines represent a two-phase system combined with the triangle representing the three-phase system. I rushed back into the adjoining room, exclaiming "I've got it." "What?" "The way to get from three-phase to two-phase." I don't think I had been away more than a minute.

Thus when the commercial necessity was presented, the engineering problem was formulated and a simple vector diagram was the key to the solution.

I was at that time preparing a paper* for the National Electric Light Association in which was described the effect of self-induction and its bearing upon

*See *N.E.L.A. Proceedings* for 1894; also THE ELECTRIC JOURNAL, Volume II, p. 713.

voltage drop in transmission circuits—a matter which was not then generally understood. The method of phase transformation was added to the paper, which was presented at Washington, D. C. on March 1st, 1894. The description then given follows:

"In considering the marked advantages of the two-phase system for distribution and of the three-phase system for transmission, it occurred to me that a combination of the two systems might secure the advantages of both, and I have worked out a simple and effective method of accomplishing this result. If two e.m.fs. differing in phase be connected in series, the resulting e.m.f. will in general, differ in value and in phase from either of its components. If two e.m.fs. differing in phase 90 degrees be connected in series the resultant e.m.f. is represented in direction and magnitude by the hypotenuse of a right angle triangle, of which the two sides are the two component e.m.fs. Thus in Fig. 1 if *AO* and *OB* are two e.m.fs. at right angles and these e. m. fs. be connected in series the resultant is the line *AB*, of different phase from either of the components.

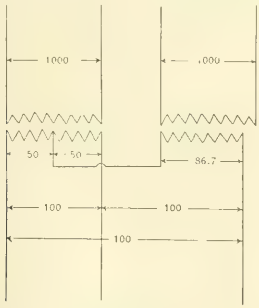


FIG. 3—APPLICATION OF TWO-PHASE, THREE-PHASE PRINCIPLE TO TRANSFORMERS

It is a simple matter to so proportion the components that *OB* is equal to one-half of *AB*, as shown in the diagram. In a similar manner it is readily seen that the same e.m.f. *OA* may be combined with *OC*, which differs from it by 90 degrees (but is equal and opposite to *OB*) in such a way as to give *AC* equal to *AB*, but differing in direction. *BO* and *OC* added together give *BC*. The e.m.f., *BC*, may therefore be combined with the e.m.f., *AO*, at right angles to it, in such a way as to give additional e.m.fs., *AB* and *CA*, which in connection with *BC*, give three equal e.m.fs. 120 degrees apart. This is the relation of e.m.fs. in the three-phase system.

"The application of this arrangement to transformers is illustrated in the accompanying Figs. 2 and 3. The primaries of two transformers are connected to a generator giving two-phase current. The secondary e.m.f's., therefore, differ 90 degrees. One secondary is made equal to 100 turns and a loop is brought out at its middle point giving 50 turns at each side. The second secondary has 87 turns, which is approximately equal to 50 multiplied by $\sqrt{3}$. One end of the secondary circuit is connected with the middle point of the secondary of the first transformer, as shown, and the three free terminals will then deliver e.m.f's. differing in phase 120 degrees. If the e.m.f. on each primary be 1000 volts and on one secondary 100 volts and on the other 87 volts, then the e.m.f. measured between any two secondary terminals will be 100 volts. This three-phase circuit is adapted for operating three-phase motors. In a system of transmission two-phase currents at the generator may be converted into three-phase currents, as shown in Fig. 4 and the windings may be such that the e.m.f. is raised for transmission. The currents are then transmitted by three phases, effecting economy in copper. At the other end of the line a similar arrangement of transformers may be used for converting from the three-phase to the two-phase system. The two-phase currents may then be used for the operation of two-phase motors or the circuits mav be independently loaded with lamps or otherwise. If lamps be placed on the transformer which supplied current directly from its two terminals, the transmission is directly from the generator without affecting in any way the other circuit, as the generator terminals are connected directly to the first primaries, and the secondaries of the raising transformer are connected directly to the

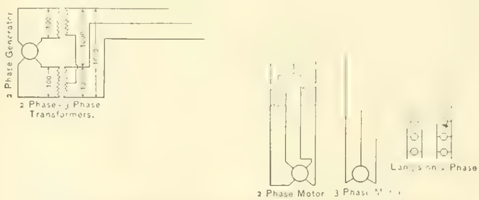


FIG. 4—THREE-PHASE TRANSMISSION FROM TWO-PHASE GENERATORS

primaries of the lowering transformer, and the current from this is taken directly to the load. On the other hand, if the other circuit be loaded, the action here will also be on its own generator circuit without affecting the first. The current from the raising transformer in this circuit passes to the middle of the secondary of the other transformer, where it divides and flows in parallel through the two parts of the coil and two of the lines. As one-half of the current flows through each part of the secondary coil in opposite directions, the self-induction is completely neutralized and the transformers in this circuit are independent of the operation of the other circuit. It is to be noted that under this condition the line e.m.f. delivered by this transformer is only 87 percent of that delivered by the first transformer. The lower e.m.f. however, is compensated for by the fact that the current on one side is passed through two of the lines in parallel, thus reducing the resistance of the circuit and compensating for the slightly lower e.m.f. The effect upon the regulation of the generator when two-phase circuits at the end of a three-phase transmission line are independently loaded is found both by theory and test, to be the same that prevails when the load is placed directly upon the corresponding circuit of the generator.

"A modification of this system is found in the arrangement where the three-phase current is produced

in the generator and transmitted over three wires to the reducing transformers. These transformers may be arranged as described for producing two phases (Fig. 5). Loads may be placed upon either of the two-phase circuits, and practically the same regulation in the generator will result that would have resulted if the generator itself had been wound for two phases and one of these circuits loaded. In this way it is possible to place a lighting load upon a three-phase generator in two instead of three units, and to avoid the bad regulation in the generator due to unequal loading.

"A similar arrangement of two transformers may be used for converting three phases of one potential into three phases of another potential, as shown in Fig. 6.

"The efficiency of two transformers arranged for converting from two-phase to three-phase is reduced below that when working independently on ordinary loads by an insignificant amount. If the efficiency in ordinary working is, say, 97.5 percent, it would be reduced to 97.4 percent in converting from one number of phases to the other.

"The Tesla polyphase system, adapts itself with marvelous facility not only to all branches of electrical industry, but also by the transformation of its phases to

FIG. 5—THREE-PHASE GENERATION AND TRANSMISSION AND TWO-PHASE DISTRIBUTION

the utilization of three phases for gaining the highest economy in transmission and of two phases for securing the maximum advantages in distribution."

One of the early applications of this method of transformation was made in connection with the first transmission lines from Niagara Falls to Buffalo. These circuits were at the time, in point of amount of power transmitted, the most important transmission of that period, although there were smaller amounts of power transmitted in some cases at a higher voltage, or over a greater distance. Transformation from the two-phase generators was made for transmitting the power to Buffalo over three-phase circuits.

In connection with the development of the transformation from two-phase to three-phase, I asked B. G. Lamme if he knew of any method of accomplishing this result. Mr. Lamme at that time was working on the construction of induction motors on the basis of distributed primary windings instead of the polar type. As was the practice in those days in alternating-current generators, a closed coil, two-circuit type of winding was tried on the earliest distributed field induction motors and there were four taps on the winding for quarter phase. He suggested in an offhand manner that the only way he could think of was to put three-phase taps on the primary winding of one of the two-phase induction motors, as with such an arrangement, if two-phase current was supplied to the primary three-phase could be taken off. However, he did not consider this a very practical scheme, and it was not deemed worth patenting. The interesting feature of the suggestion is that this additional method of phase transformation is the only one, aside from the use of transformer connections, which has since been used to any extent.

I had previously noted that when a two-phase induction motor is running idle with one circuit open, so that it is being supplied with single phase, there is a voltage on the terminals of the idle winding of the motor which is approximately equal in value, but is 90 degrees from the impressed voltage on the other circuit. The idle motor was therefore a phase converter and the voltage of its idle winding, combined with the voltage of the supply circuit, furnished two voltages differing 90 degrees which constitute a two-phase circuit and could have been employed for operating small two-phase motors. At the time it did not occur to me that

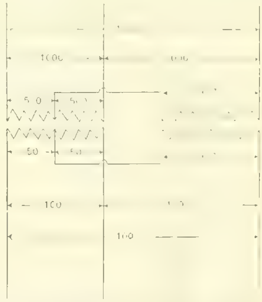


FIG. 6—THREE-PHASE TO THREE-PHASE TRANSFORMATION WITH TWO TRANSFORMERS

this principle was one which might be useful. It is at present, however, being employed on the electric locomotives of the Norfolk and Western Railroad which are the most powerful electric locomotives in service. On these locomotives, the single-phase trolley supplies current to a rotative phase converter which is in fact a two-phase induction motor operated from one phase only and producing in its second winding a ninety degree electromotive force which, in conjunction with that of the trolley circuit, constitutes a two-phase supply to a pair of transformers for transforming from two-phase to three-phase. The three-phase circuit then operates the three-phase propulsion motors.

Possibly if a commercial need for this sort of transformation had been definitely presented, the importance of this transformation from single-phase to polyphase by an idle induction motor might have been recognized years earlier. Under the circumstances, however, a patent would never have amounted to much, so far as the locomotives are concerned, as they were not built until after the patent would have expired.

The Essentials of Transformer Practice-XVIII

Phase Transformation

E. G. Reed

THE most important transformer connections for phase transformations are:—

1—Three-phase to single-phase.
2—Three-phase to two-phase.
3—Two phase to six phase.
4—Three-phase to six-phase.

This discussion does not go into detail regarding the vector relations of the voltages and currents, nor the k.v.a. capacity of transformers required for the different arrangements, but merely shows the connections required to give the transformations.

THREE-PHASE TO SINGLE-PHASE

It is impossible to deliver single-phase current from a three-phase source of supply and have balanced conditions. If this were done it would mean that the continuous flow of power from the three-phase source passing through the transformers would be changed to a flow of single-phase power passing from a maximum through zero and back to a maximum every half cycle. As this is impossible with static transformers (i.e. with any apparatus which has no capacity for storing energy at one time and subsequently giving it out) it is apparent that such a transformation is also impossible.

Various schemes have, however, been proposed for this transformation but none of them gives better results than connecting a single-phase transformer across one of the three phases. In the case of a star connected source of supply, this gives an equal current in two of the phases and zero current in the third. With a delta connected source, two of the phases have the same current and the third a current twice as large as that in the other two. The current therefore has a better distribution with a delta connected than with a star connected source of supply.

THREE-PHASE TO TWO-PHASE

A number of schemes for three-phase to two-phase transformation have been devised, but the most commonly used is the Scott connection shown in Fig. 1, which requires two transformers. In the three-phase side, the number of turns in the teaser winding is 86.6 percent of the number in the main winding. In the two-phase side, the windings of both transformers are identical and independent, when supplying a two-phase four-wire circuit. For the sake of interchangeability the main and teaser transformers are usually made identical, that is the three-phase windings are provided with both a 50 and an 86.6 percent tap, as shown in Fig. 1. When operating as the main transformer, the 50 percent tap is used; and when as the teaser the 86.6 percent tap, the 13.4 percent part of the winding being idle in the latter case. Each of the two halves of the three-phase winding should be distributed over the entire winding length of the magnetic circuit in order to prevent flux distortion and the resulting poor regulation.

A connection is sometimes used in emergency cases where a transformer with an 86.6 percent tap is not available and a teaser transformer of the same voltage as the main transformer must be used. In this connection two transformers of exactly the same capacity and voltage are used. With this arrangement the phases are not exactly 120 degrees apart, and an attempt to operate it in parallel with a true three-phase circuit will result in unbalanced currents.

In these two Scott-connected transformations, the two-phase windings are electrically distinct. There are, however, a number of schemes in which the windings on the two-phase side are electrically interconnected, as shown in Figs. 2 and 3. In both of these transformations the three-phase side of the transformers may be connected in star or delta as desired. When a three-phase to two-phase transformation is desired in a single unit, instead of two or three transformers, either of the arrangements shown in Figs. 2 and 3, may be used with a three-phase magnetic circuit. This connection is desirable when the special design of the single unit is not objectionable, as compared to the more standard single-phase transformer used for the Scott connection.

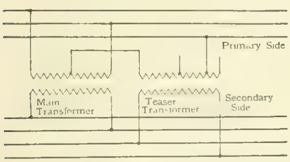


FIG. 1—SCOTT CONNECTION FOR THREE-PHASE, TWO-PHASE TRANSFORMATION
With duplicate single-phase transformers

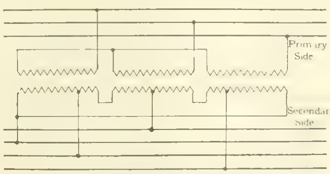


FIG. 2—THREE-PHASE, TWO-PHASE TRANSFORMATION
Using three single-phase transformers, with the two-phase side interconnected.

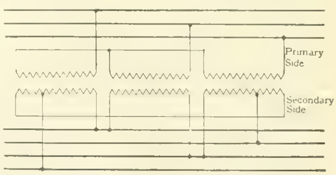


FIG. 3—TRANSFORMATION FROM THREE-PHASE TO TWO-PHASE
Three single-phase transformers with the two-phase side interconnected.

THREE-PHASE TO TWO-PHASE AND THREE-PHASE

By connecting to the corners of the delta on the secondary side of the arrangements shown in Figs. 2 and 3, three-phase current may be drawn from the transformers simultaneously with the two-phase current. The voltage however of the two-phase and three-phase circuits will be different. A connection giving the same voltage two and three-phase on the secondary side is shown in Fig. 4. This is the T-connection for the three-phase transformation, and Scott connection for the three-phase to two-phase transformation.

TWO-PHASE TO SIX-PHASE

The double Scott connection shown in Fig. 5 is used where a six-phase synchronous converter is to be operated from a two-phase supply system. This transformation requires two special transformers of the same impedance, each having two low voltage windings, connected so that their voltages are 180 degrees from each other in phase relation in order to give the six-phase system. Obviously, considerable complication of starting taps and switches results, often to such an extent that the two units cannot be made exact duplicates of each other. In case the neutral must be brought out on the six-phase side the complications are increased.

THREE-PHASE TO SIX-PHASE

The Diametrical Connection, shown in Fig. 6, is commonly used for the three-phase to six-phase transformation. It requires one low-voltage coil on each transformer which is connected to diametrically opposite points on the converter winding. It gives a simple arrangement of taps and switches for starting the converter, and continued operation at reduced capacity is possible with one transformer out of service. With diametrically connected low-voltage windings, the high-voltage windings may be connected in star or delta, although the delta connection is usually preferable. The middle points of the diametrical windings can be connected together and brought out for the three-wire direct current service, as the unbalanced three-wire direct current does not give a distorting effect. Arrangements should then be made for opening the neutral connections when starting, to avoid short-circuit.

With a six-phase diametrical connection with common neutral, one-half the output can be taken from the low-voltage side for operating three-phase without change of diametrical voltage. If full three-phase output should be desired, the coils can be connected in delta, in which case the diametrical voltage is increased 14 percent. The full three-phase output at 1.73 times the diametrical voltage may be obtained by connecting the coils in star, in which case the neutral should be grounded. When full output is required at the same voltage at either three-phase or six-phase, the double delta connection is usually used.

The Double-Delta Connection requires two independent low-voltage windings on each transformer as in Fig. 7. Both are connected in delta, but one set is reversed as compared to the other, so that the two deltas are displaced 180 degrees in phase relation from each other. The high-voltage side should be connected in delta as this permits operation with two transformers in case the third should become damaged. Full output three-phase may be obtained by connecting the two halves of the secondary winding of each transformer in parallel, and the three parts thus produced in delta. The double-delta connection cannot be used for three-wire direct-current service, and in this case separate autotransformers would be required to obtain the neutral point.

The Double-Star Connection, like the double-delta, requires two sets of low-voltage coils, displaced 180 degrees in phase relation from each other as in Fig. 8. The high-voltage windings may be either delta or star connected, but perferably the former.

The Double-T Connection for transforming from three-phase to six-phase is shown in Fig. 9. Like the double delta and the double star connections, two sets of low-voltage coils displaced 180 degrees in phase relation from each other are required. The two high-voltage windings are connected in T.

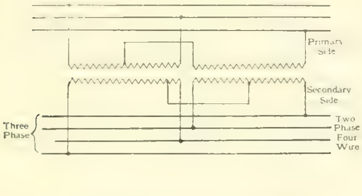


FIG. 4—TRANSFORMATION FROM THREE-PHASE TO BOTH TWO-PHASE AND THREE-PHASE
With two single-phase transformers.

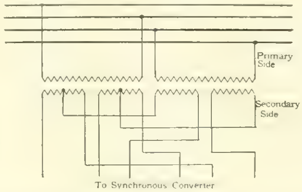


FIG. 5—SCOTT CONNECTION FOR TWO-PHASE, SIX-PHASE TRANSFORMATION
With two single-phase transformers.

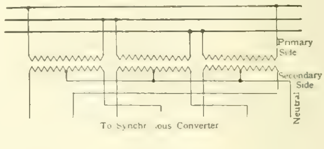


FIG. 6—DIAMETRICAL CONNECTION FOR TRANSFORMING FROM THREE-PHASE TO SIX-PHASE
With three single-phase transformers.

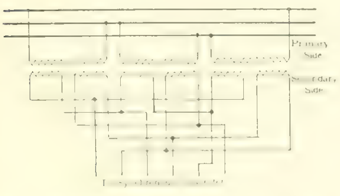


FIG. 7—DOUBLE DELTA CONNECTION FOR TRANSFORMING FROM THREE-PHASE TO SIX-PHASE
With three single-phase transformers.

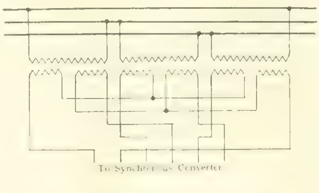


FIG. 8—DOUBLE STAR CONNECTION FOR TRANSFORMING FROM THREE-PHASE TO SIX-PHASE
With three single-phase transformers.

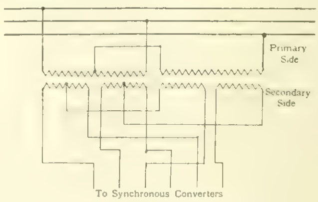


FIG. 9—DOUBLE T CONNECTION FOR TRANSFORMING FROM THREE-PHASE TO SIX-PHASE
With two single-phase transformers.

Notes on Large Steam Turbine Design

J. F. Johnson

THE remarkable growth of the electric power industry during recent years has been paralleled by an equally remarkable growth of steam turbine driven generating units. So rapid has this development been that frequently before the first machine of a new design was completed another of materially greater capacity and higher efficiency was being designed.

While machines of 15 000 kw capacity were put into operation as early as 1908, their use did not become general until 1913; whereas today nearly every one of what may be called our large generating stations has at least one unit of 30 000 kw capacity or larger in service or on order.

In our chief cities, which are also our chief industrial centers, the electric power industry has attained its broadest development. Here the density of power consumption, that is, the rate of consumption per unit of area, has reached high values. These high densities of consumption encourage the formation of large public service companies, both by means of development, and by means of the consolidation of smaller ones.

In Table I roughly approximate figures are given showing for several districts, each included within a circle of about ten miles radius; first, the sum of the maximum sustained peak loads supplied by all the public service companies operating within that district during the year of 1917; and second, the total capacity in kilowatts of generating units which will have to be installed by 1920, based upon an estimated increase of peak load of eight percent each year and a surplus of generating capacity installed above peak load of twenty percent.

In the selection of sizes of generating stations the choice of sizes of generating units will materially affect the total cost of power generated. If the sizes of units be too small and the number too large, the cost per kilowatt of the station completed will be greater, the maintenance and operating expenses higher, the efficiency poorer, and reliability at least no greater than if the proper sizes are used. On the other hand, if the units be too large, the cost per kilowatt installed may be too large because of the greater reserve or stand-by capacity required and the efficiency may even be poorer by reason of the units operating at loads too far below their points of best efficiency.

Take for example a district with a maximum peak requirement of 600 000 kw which, to insure proper reliability, it is decided to generate in three stations of approximately equal sizes. Assume that these stations will normally always operate in parallel with each other, and that there will be one spare unit for each five in service during the peak. If 20 000 kw units are used, there will be thirty operating and six spares, making a total of 36 units, twelve in each station. If 30 000 kw units are used, there will be a total of twenty operating and four spares, making a total of twenty-four units, eight in each station. If 40 000 kw units are used, there will be a total of fifteen operating and three spares, making a total of eighteen units, six in each station. If 60 000 kw units are used, there will be a total of ten operating and two spares, making a total of twelve, four in each station.

If, in order to remove from this consideration of ideal size of units conditions imposed by the design of the apparatus, it is assumed that irrespective of the size the reliability, efficiency, and purchase price per kilowatt will be the same, it should be obvious that the 20 000 kw size is too small and that best results are to be expected with either the 40 000 or 60 000 kw sizes, because the installation costs, including buildings, foundations, piping, and switching equipment, and operating costs, including maintenance supplies and attendance would be less per kilowatt; the efficiency higher because of the higher efficiency of the larger units, larger auxiliaries and smaller friction and radiation losses in the larger steam and water piping; and reliability greater because of the smaller number of operations of starting and stopping and cutting in and out of service of units necessary.

So far as conditions affected by the design of units is concerned, in sizes up to at least 30 000 kw capacity, higher efficiency at the same cost per kilowatt is obtainable purely by reason of the larger size and still higher efficiency for a slight increase in cost per kilowatt, and it has been quite conclusively demonstrated that as high a degree of reliability is obtainable in these larger units as in the smaller ones. The approximate relative steam consumption rate of units in sizes varying from 5000 to 40 000 kw, all designed for the same cost per kilowatt, is shown in Fig. 2.

While districts in which the peak requirements of any one operating company are as great as from 400 000 to 600 000 kw are at the present time not numerous, there are many which will probably reach that stage before installations being made at this time are expected to become obsolete. In these, units of the larger sizes should be introduced to replace smaller ones as they become obsolete and to take care of increasing requirements at such a rate as will effect the most economical production of power over the estimated period of usefulness of the machines installed. Numerous generating stations of around 200 000 kw, installed capacity, projected and designed by the ablest engineering talent in the country, are under construction and in operation, and units of 30 000 kw and larger are being employed in them; also stations of approximately 300 000 kw installed capacity are being projected and will probably be built in the near future.

Appreciating the need of generating units of large capacities in the future growth of the electric power industry, the engineering staff with which the writer is associated several years ago took up the work of designing such machines, assured themselves of their feasibility, and advocated their use. A number of them

*Revised by the author from a paper before the Philadelphia Section, A. S. M. E., Nov. 26, 1918.

have been in operation several years, and their expected excellence as to reliability and efficiency has been fully verified.

Up to the present time a total of fourteen units have been sold, varying in capacity from 30 000 to 70 000 kw maximum. Of these eleven have been shipped, ten are in service, and seven have been in service for periods varying from approximately one to five years. The records of performance of these machines should emphatically remove any doubt as to the commercial possibility of units of large capacity, and satisfactorily prove that at least within limits not yet reached, increase in size need not impair reliability, and may improve efficiency.

OPERATING RECORDS

The first three of these units were sold to the Interborough Rapid Transit Company of New York. They are duplicates, of the two cylinder, cross compound, pure reaction type, and designed for maximum reliability and efficiency. They have a maximum rating of 30 000 kw with the point of highest efficiency at 25 000 kw, operating with 205 pounds steam pressure, 120 degrees F. superheat, 29 in. of vacuum referred to 30 in., the high-pressure element operating at 1500 r.p.m., and the low pressure at 750 r.p.m. The first unit was put in service December 30th, 1914, the second in February and the third in August, 1915. Very elaborate and exact steam consumption tests were conducted on the first of these units.*

These units, since their installation, have been operating on an average of from sixteen to twenty hours per day, on fluctuating railway loads varying from 10 000 to 30 000 kw. With the first and third no troubles of any sort have been experienced and they have been ready at all times for any service within their designed capacity except when out of service for regular periodic inspection, or ordinary maintenance. On the second the labyrinth packing on the balance pistons of the high-pressure element has failed three times, requiring renewal of some parts. The cause of these failures was at first supposed to have been improper adjustment, but investigations following the third failure indicated excessive lost motion in the thrust bearing and heavy distortional stresses, caused by rigid bracing of the steam pipe near the turbine as the probable causes.

The fourth unit, placed in operation in the Northwest Station of the Commonwealth Edison Company, Chicago, in September, 1917, consists of a tandem compound, pure reaction turbine, direct-connected to a single generator. It has a rating of 30 000 kw with an additional overload capacity of 5000 kw operating with 220 pounds steam pressure, 200 degrees F. superheat, and 29 in. of vacuum, 1200 r.p.m.*

A few hours after being put into service, subsequent to completion of erection, the labyrinth packing on the low-pressure element failed, due, we think, to buckling of the cylinder, caused by rigid piping connections between the two surface condensers, which were bolted rigidly to the two exhaust openings on the turbine, preventing the condensers from translating with the turbine as its temperature increased. Temporary re-

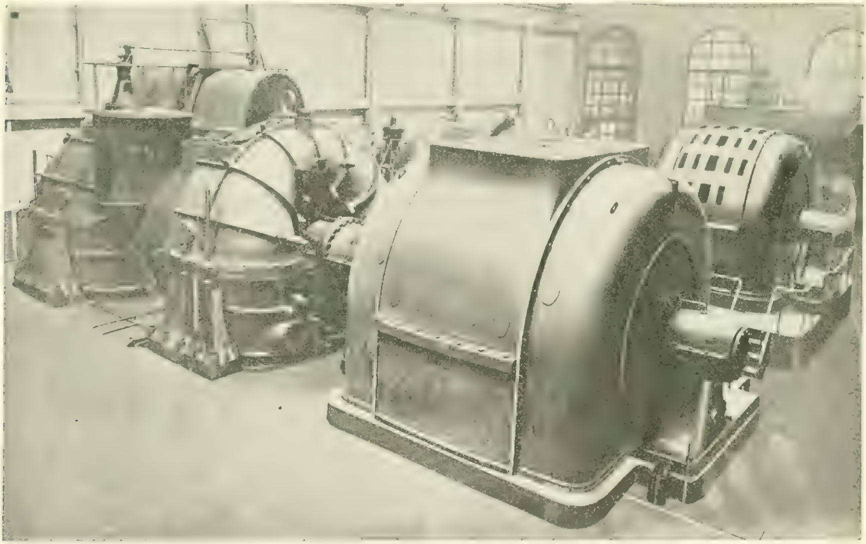


FIG. 1 30 000 KW SINGLE CYLINDER TURBINE IN THE GOLD STREET STATION OF THE BROOKLYN EDISON COMPANY

*See article on "Efficiency Tests of a 30 000 Kw Cross-Compound Steam Turbine" by H. G. Stott and W. S. Finlay in the JOURNAL for July, 1916, p. 335.

*For a detail description see article on "The New Commonwealth Turbine" by J. F. Johnson, in the JOURNAL for June 1918, p. 192.

pairs were made locally and the unit put in service in about four weeks. It has been operating almost continuously since without trouble of any sort, (except cracking of a copper expansion joint), carrying loads as high as 40 000 kw. In one instance it was kept on the line for seventy-one days, and then taken off only in order to clean the condenser. Material for making permanent repairs to the labyrinth packing was shipped to the station within a few months after the accident, but permission has not yet been given to take the unit out of service long enough to install it.

The fifth unit, a 30 000 kw pure reaction single cylinder machine, operating on 200 lbs. steam pressure, 100 degrees superheat, 29 in. vacuum, was placed in operation in the Gold Street Station of the Edison Electric Illuminating Company of Brooklyn, in October, 1917. Owing to congestion in the shops and urgency of shipment, this turbine was not operated prior to shipment. The overspeed test was made after installation. No correction of balance was necessary, and with the exception of a few leaks in the oiling systems, and the breaking of a defective gear on the oil pump drive, no

TABLE I—LOAD CAPACITIES OF ALL COMPANIES

District	Sum of Max. Sustained Peak Load, 1917	Total Capacities to Be Installed by 1920
New York	800 000	1 190 000
Chicago	400 000	596 000
Philadelphia	250 000	373 000
Buffalo and Niagara Falls	300 000	447 000
Detroit	155 000	231 000
Boston	155 000	231 000

trouble of any sort has been experienced. It has been available for service at all times, and has been operating almost continuously except over Sundays and when necessary to clean the condensers, at average loads of approximately 23 000 kw, and peak loads as high as 32 000 kw.

The sixth unit, placed in service in December, 1917, in the Kent Avenue Station of the Brooklyn Rapid Transit Company, is a duplicate of the fifth machine. Just after installation some rebalancing of both turbine and generator rotors was necessary. This unit was opened in July, 1918, at which time a few rows of high pressure blading were found damaged. Also some injury to the glands had occurred, requiring new gland parts. On October 18th, after having been in service approximately ten months, the thrust bearing overheated and wiped some, but did not damage any other part of the machine. When opened for inspection it was found that the labyrinth packing strips, which were made of an aluminum alloy, were considerably corroded by the action of strong alkalies used at this plant for treating feed water; and two rows of blading in the high pressure portion of the machine were found to have been damaged at some previous time, caused probably by foreign matter or a defective blade. This machine was in regular service up to October 18th, carrying maximum loads as high as 31 000 kw, and an average of 25 000 kw.

The seventh unit is a 40 000 kw, 60 cycle, cross-compound machine, installed in the Brunot's Island Station of the Duquesne Light Company,* at Pittsburgh, and was placed in service in December, 1917. The high-pressure element of this machine operates at 1800 r.p.m. and the low-pressure at 1200 r.p.m. This unit has been in regular service carrying loads normally of from 30 000 to 40 000 kw, with peaks as high as 50 000 kw. On February 18th, while operating the machine to correct the balance of one of the generators, the main bearing at the coupling end of the high-pressure turbine burned out, apparently due to interruption of oil service to that bearing. This let the spindle down sufficiently to cause rather heavy blade rubs throughout the machine. The bearing was re-babbitted and the machine put back in service without any other work being done except rechecking the clearances and placing a balance weight on the spindle to correct for the weight rubbed off the blades. In July the generator was damaged by an external short-circuit, and while the repair was being made, both elements of the turbine were dismantled. The high-pressure rotor was returned to the

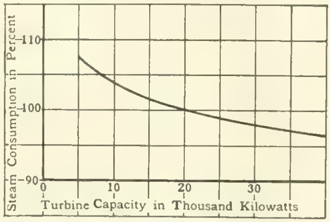


FIG. 2—RELATIVE STEAM CONSUMPTIONS OF LARGE CAPACITY TURBINES

shops, the damaged blading replaced and rebalanced. New blading was also installed in the stator to restore the original clearances and original efficiencies. Inspection of the low-presure element revealed several broken blades which were defective and had slightly damaged the rest of the blading in those rows, requiring replacement of approximately 1.5 rows of blading on each end of the machine. This unit is now operating with some of the blades in the last stage of the high-pressure turbine missing, the blades having come out of the grooves when the machine was operated at 20 percent overspeed, following the blading repairs in July. Upon investigation an error in the detail design was discovered; the rim thickness of the blade carrying element was unnecessarily made too small at the last row, so that the stresses through the groove in the last row became excesive. A new blade carrying element is being made and will be installed to correct this error.

The eighth unit, practically a duplicate of the seventh, rated at 45 000 kw maximum, was placed in service for the Narragansett Electric Light Company in

*For a detail description see article on "45 000 Kw Cross-Compound Steam Turbine of the Duquesne Light Company," by J. P. Rigsby, in the JOURNAL for Nov. 1918, p. 435.

Providence in January, 1918. In placing this machine in service the labyrinth packing on the high pressure was damaged, due to improper adjustment, which necessitated temporary repairs, keeping the machine out of service until about March 1st. Since then no trouble has been experienced except some distortion of the couplings caused by a series of violent short-circuits, and some defective workmanship on the fitting of the coupling keys. Permanent repairs to the labyrinth packing have been made and new coupling parts are to be installed in the near future. In the meantime the old parts are operating satisfactorily without any evidence of distress. This machine operates on loads as low as 5000 kw, and has carried a peak load of 50 000 kw for periods of from four to five minutes.

The ninth unit is a 70 000 kw, three cylinder, cross compound, 25 cycle machine, installed for the Interborough Rapid Transit Company in New York. One low-pressure element was placed in service April 18, 1918, operating on high-pressure steam. The high-pressure element was placed in service August 21st, operating in connection with the low-pressure element already installed, and the second low-pressure element was placed in service October 9th. Some intermittent vibration trouble appeared on the first low-pressure machine, the cause for which was found to be lack of sufficient clearance on one of the spindle rings, causing distortion during expansion. After this was corrected no further trouble was experienced except the breaking of a few defective blades on the intermediate stage of the second low-pressure element. This unit is equipped with an automatic control mechanism for cutting any element out of service, either automatically or manually, without disturbing the other two. These features have been given a thorough try out which, so far as a demonstration goes, has verified all expectations as to flexibility of this feature. In regular service it has carried loads as high as 55 000 kw, with swings up to 61 000 kw.

While these records do not all show 100 percent perfection in all respects, they do show that in not one instance has there been any evidence of inherent or basic defects in design or difficulties in construction or operation. Some troubles have been experienced but these have all been of minor character, due to avoidable defects in detail design, construction, installation, or operation; such as are experienced with new designs of any size or sort. The detail design of the labyrinth packing, which has caused most of the trouble, has been modified so that contact in the labyrinth packing, due to distortion or improper adjustment will not result in injury to the machine, nor require its immediate removal from service. It is significant that with one exception no important part of any one of these units has ever been returned to the works for replacement, alteration, or repair. The high-pressure rotor of the Duquesne Light Company unit was returned to the shops for checking for truth and reblading. While most of them have not been subjected to any accurate steam consumption tests, definite reductions in station coal consumption rates were affected by their installations.

TURBINE DESIGN PRINCIPLES

The foregoing discussion naturally leads to a consideration of some of the more important problems of large steam turbine design, and of their solutions. The theoretical or thermodynamic design of a steam turbine is in itself quite simple. The proper steam path for any assumed rate of steam flow, giving the number of stages and areas through each for any given or assumed blade velocity or velocities and assumed ratio of steam velocity to blade velocity may be determined with the aid of a steam table or sufficiently accurate Mollier diagram, giving specific volumes. To the above then need only be added a speed regulating device, consisting of some form of centrifugal governor controlling a steam inlet valve, and an oiling system.

The successful practical design, however, is quite involved, comprising many problems worthy of the highest engineering skill. Many conflicting factors must be most judiciously combined in order to secure the best evenly balanced design and one which will serve the purpose for which it was intended most usefully.

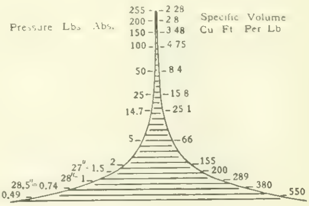


FIG. 3—DIAGRAM SHOWING THE SPECIFIC VOLUMES OF STEAM AT VARYING PRESSURES

In this as in all other arts, carefully studied and accurately judged experience is the great teacher, and highest success is attained only after years of growth, adhering to the same basic design, the principles of which must be right and therefore susceptible of the highest development.

To begin with, the engineer must have a clear vision of his ideal, his turbine made perfect in every detail. This must be the standard toward which he constantly strives, deviating from it only as compelled to do so in compromising between conflicting factors. In this ideal, reliability and general operative excellence must stand out as the dominating characteristics, because above all things the machine must be dependable to deliver its rated capacity of kilowatts upon demand; second to this comes efficiency because it must, in competition with other units, yield a profit for the owner; and third comes cost, because the unit must be salable in competition.

The first and perhaps greatest single problem is suggested in the theoretical design, viz., that of providing areas suitable to accommodate the enormous increase in volume of the steam while passing through

the turbine. Steam supplied at the throttle at 250 lbs. gauge pressure and 150 degrees F. superheat enters the first stage at a pressure of about 255 lbs. absolute and a specific volume of 2.28 cubic feet per pound, (allowing ten lbs. drop through the throttle and inlet valves). It leaves the last stage at 380 cu. ft. per pound when a 28.5 in. vacuum is maintained by the condenser, and 550 cu. ft. per pound when a 29 in. vacuum is maintained; that is, the volume when exhausting to 28.5 in. vacuum is 166.5 times, and when exhausting to 29 in. is 241 times as large as it is at the entrance. This means that if the rate of steam flow is such as to require an 18 in. steam inlet pipe, and if its velocity were maintained the same through the exhaust as through the inlet pipe, the exhaust opening when expanding to 28.5 in. vacuum would have to be 19 ft., 4 in. in diameter, and when expanding to 29 in. vacuum, 23 ft., 4 in. in diameter, or if the mean diameter and exit angle of all the rows of blading be the same and the ratio of blade speed to steam speed be the same in each, thereby keeping the theoretical efficiency of all stages equal, and if these blade and steam speeds be so chosen as to fix the height of the blades in the first stage at one inch, the last row would have to be approximately 13 ft. 10.5 in. if designed for 28.5 in. vacuum, and 20 ft., 1 inch if designed for 29 in. vacuum. This enormous increase in volume is shown in Fig. 3. The impracticability of adhering to such proportions in actual designs is obvious.

Here is where the combining of conflicting factors begins. In the first stages the areas and blade heights should be kept large in order to reduce the losses, and in the low-pressure stages the desirable sizes must be sacrificed on account of practicable limits of mechanical design. In single cylinder machines where the blading is all on the same spindle, the problem becomes doubly difficult.

The first determination is that of rotative speed, which is usually not difficult to make, since the frequency of the generator restricts the permissible speeds to a few and these are rather widely separated. The limiting capacities at the various permissible rotative speeds for which generators can be built must also be considered, although at the present time the practicable limits of turbines and polyphase generators are reached at approximately the same capacities.

The chief factor in the selection of the rotative speed is the design of the last row of blades with reference to height, diameter and exit angle, because this is the most important stage in the whole turbine. In it the mechanical stresses and fatiguing effect of vibration, the B.t.u. drop, and physical dimensions, are all greatest. Consequently, upon it depends largely the reliability, efficiency, and cost of the unit.

Here the temptation of reward in high efficiency without appropriate higher cost, by departing from known reliable and conservative practice in the employment of materials and stresses, is greatest, and the engineer must needs keep both eyes firmly fixed upon his ideal, lest he be led astray by the alluring appeals of a daring commercialism. Here must be considered the alternatives of a higher rotative speed with the low-pressure stage made multiflow as against a slower rotative speed and single flow construction. The length of blades must not be excessive with reference to the diameter, not only because of the higher stresses in the blades and rotor, but also because the difference in velocity of the blades at their tips and at their roots, as well as, the difference in blade spacing will, if too great, materially impair the efficiency.

On the other hand, if the area through the blades is too much restricted, the steam velocity will become too high and the bearing losses too great. If this restriction is carried to the extreme, the steam in passing through the last row of blades may even reach its critical velocity without expanding entirely down to the condenser pressure, in which event the remainder of the expansion takes place in the form of an explosion upon leaving the blade passages, and from it only a small percentage of the energy is recovered.

In order therefore to secure the most satisfactory design for the last stages, and in order to prevent the stresses or physical dimensions with the ever present cost from becoming prohibitive, several compromise features are employed. The first of these consists of increasing the rotor diameter and blade heights, if necessary, until the safe limit of stress is reached, keeping the blade height within approximately one-fourth of the rotor diameter as a limit of good practice. The materials of which the rotor and blades are made will of course determine the safe stresses, and on account of the great importance of safety and reliability in these parts, only good quality of plain, or five percent nickel low carbon steels should be used, because these are commercially common materials, uniform in quality and do not require sensitive heat treatments.

For rotors, cast or forged steel having a tensile strength of 70 000 lbs., true elastic limit of 28 000 to 30 000 lbs., and elongation of 18 percent in two inches may be stressed to 20 000 lbs. per sq. in., and for blades, five percent nickel steel having a tensile strength of 85 000 lbs. and true elastic limit of 35 000 lbs., may be stressed to 25 000 lbs., both at 20 percent overspeed. The stresses at normal operating speed will therefore be 13 900 and 17 350 lbs. respectively, and the factor of safety against rupture approximately five.

Increasing the diameter not only permits increasing the blade height, but also the steam speed without materiallly affecting the efficiency, by reason of the increase in blade speed. There is, however, a slight falling off in efficency with the higher speeds, even though the ratio of blade to steam speed be kept practically constant, because the actual velocity of the steam with reference to the blade being greater, the frictional losses will be greater.

The second compromise consists of increasing the steam passage area through the blades by changing the blade shape (Fig. 4). This change increases the angle between the direction of steam flow from the blade and the direction of the blade, and a slight impairment of

efficiency results therefrom. However, this loss is slight compared to the gain from the higher ratio of blade speed to steam speed resulting from the increased area. This practice is standard on practically all condensing machines built for high vacua.

The third compromise consists of permitting the steam speed to increase without a corresponding increase in blade speed, thereby decreasing the ratio of blade speed to steam speed, and increasing the leaving losses. This compromise may properly be employed up to the point where the loss of efficiency will justify the increased expense of greater blade areas, which may necessitate dropping to a lower rotative speed, or employing multiple stages.

Two or more low-pressure stages in multiple, in connection with a single high-pressure stage, are used when the required areas cannot be obtained with a single stage element at the rotative speed chosen, and when it is more feasible to employ multiple stages than a lower rotative speed. Other considerations favoring multiple

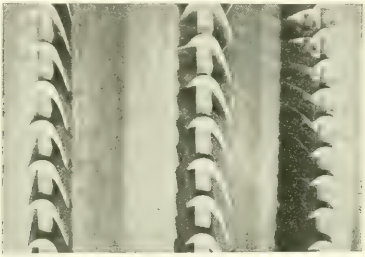


FIG. 4—SPECIAL SHAPED BLADES IN LAST ROW
To secure greater area without increase in height.

stages are (1), reduced physical dimensions of the exhaust chambers, simplifying both the ribbing and bracing necessary to maintain the proper rigidity; and the cylinder supporting structure, including foundations; and (2), limitations of shipping dimensions established by transportation companies.

The design of the higher stages usually involves only an equitable selection of diameters, blade speeds, and steam speeds. Keeping these low results in low stresses and high efficiency, but large number of stages, and high cost; while keeping them high reduces the length, weight, and cost, but increases the stresses and impairs the efficiency.

If the steam volumes in the first stages are relatively small for the rotative speed employed, as would be occasioned by the use of high steam pressure or low rating, a double velocity stage impulse element may often be employed to advantage; the advantages secured being reduction of length, increased diameter, reduced pressure and temperature inside the main cylinder, and adaptability for varying overload capacity, but not increased efficiency nor decreased cost.

Having fixed the rotative speed to secure proper design of the low-pressure stages, and the diameters and steam speeds of the high pressure stages to give the highest economy, the length of the rotor may become excessive, necessitating its division into two parts in order to maintain requisite reliability. These parts may be arranged either in tandem form, driving a single generator, or in cross-compound form driving two generators. When arranged cross compound it will often be found advantageous to increase the rotative speed of the high-pressure element, thereby gaining reduced physical dimensions, weight, and cost, without sacrifice of efficiency or reliability. The multi-cylinder construction is especially desirable in the employment of high steam pressures and superheats in that the high-pressure turbine structure is small, and there is no danger of stress complications resulting from wide temperature differences and no transmission of heat through the cylinder walls from the high-pressure to the low-pressure stages. It has a further advantage in these days of increasing steam conditions in that a unit may be designed for given steam conditions and later redesigned for materially higher conditions, the redesign being entirely carried out in the high-pressure element.

In units of 60 000 kw or larger, the three-cylinder cross-compound construction employing one high-pressure and two low-pressure elements, possesses the advantages of high efficiency and reliability without employing excessively large structures, and has greater flexibility than is possible with either of the other constructions. This flexibility, enabling the high-pressure element to operate with either low-pressure element, or either of the three elements to operate alone, admirably adapts it for use in systems not yet large enough to permit employing a single unit of so large capacity. These units may be provided with a control mechanism by means of which either of the elements may be taken out of service either automatically or manually, through the operation of circuit breakers or automatic stop governor, and the remaining ones will continue to operate, carrying loads up to be maximum ratings of their generators. The low-pressure elements, when operating on high-pressure steam direct, may be made to carry loads for short periods considerably in excess of the rated capacities of their generators.

The present and prospective future growth of the electric power industry requires generating units of large capacities. Such units have been built and are commercially successful; and there appears to be no engineering, manufacturing, nor economic hindrances to their general use. As in all other commodities, the supply of turbine generating units, both with respect to capacity and quality, will be very largely determined by the demand. Competition will force the manufacturer in designing and building these machines, to give the same relative importance to their three chief characteristics as is given them by the purchaser when buying. The engineer's ideal cannot be attained unless the purchaser, after critical analysis, insists upon reliability and general operative excellence as of first importance; efficiency second; and cost third.

Dad, the Inspector, on Cooperation

L. J. Davis
Railway Dept., Westinghouse Electric & Mfg. Company,
Detroit, Mich.

WELL, Dad, I guess I'll quit this job an go some place where they got some o' that co-operation the old man was talkin' about in the meetin' the other day. You can't get none in this hole. All these guys is out fur number one and nobody else. You've worked in a lot o' shops, where is there one where they got some?"

"Son", the old man said, "you said somethin', an' as this is the last Sunday we're gonna have it easy till long after New Years, I'm gonna preach a little to you and these guys that's allus hollerin' about every place bein' better'n the one they work in."

The old inspector whittled off some shavings of natural leaf, filled his pipe and when it was going well, started in.

"This here matter of co-operation is ginerally looked at, as the Good Book says, through a glass darkly. You hear a lot about it from guys you think knows all they is to know on the subjeck an you come away all lit up with the idee that they has give you a new kind o' grease that's a gonna make things run smooth and never have to be give no attention. From now on the other guy is a gonna see things jes' like you see 'em and they ain't gonna be no more argements. Things is shore gonna run smooth."

"Right here I wanta tell you, Jack, and you other mourners that is a listenin' to this here sermon, that when two cog wheels is a runnin' together they both gits wore, and when you puts grease on 'em it is callated to help 'em both, not only one."

"This here word co-operation means just one thing and nothin' else,—workin' together. This here universe is a runnin' as a combination o' things, but not people, jes' workin' together. Them there stars you see at night is all different, but they works together. The sun and the rain worked together to make that there red apple you're eatin', Jack. You never see none o' them things doin' a mite more'n their stint, though."

"We don't deserve no more credit fur jes' workin' together than we do because we breathes the same air, if we all sleeps together in the same room. None of them things is up to us. We got to do it whether we wants to or not because its all part of a plan fur this ol' world."

"But, Dad, that ain't the kind o' co-operation the old man talked about at all. He said we needed co-operation to be happy. He said co-operation was somethin' we needed and was hard to get an' if we got it we deserved a lot o' credit 'cause it took a lot o' tryin'. Now you come along and say it ain't our fault at all that we got it, cause it was wished on us anyhow. I don't git you, Dad, at all."

"Well, son you jes' listen a mite longer and I'll make it so clear even you can see it. See that there axle bearing. They is a iron shell and a babbitt linin'. Them two metals is co-operatin'. Somebody put 'em together and they can't help makin' a bearing. Take a little look at the end. See that crack between the babbitt and the iron. They is separated a wee mite. They make a pretty fair bearing at that till a little oil or water gits between 'em, and they separate further. The babbit gits loose and quits the job cause the work is too hard and it ain't gittin' its idee of co-operation from the iron, and trouble begins."

"See that there other bearing. That's a brass bearing with a babbitt linin'. You don't see no crack between them two. No sir! them metals is not only co-operatin' because some guy poured 'em together but they is amalgamatin'. They've got so close together on the job that one is a part of the other and when the babbitt is wore down it don't try to slip out and leave it up to the brass, it sticks and the brass takes more load than it signed up for and don't holler till the whole works is all het up—until it's done all it can. That's what the old man was tryin' to get into you guys, not co-operatin'—you got to work together either here or some place else—but amalgamation. The idee of this job bein' up to you, an' that job up to me, with the rottenest job ginerally up to you, is co-operatin' or jes' workin' together. The idee of every job bein' up to us, with a leetle the biggest end on me is amalgamatin'."

"But, Dad, that ain't no fault of the babbit an' the brass. They nacherly amalgamates. Take me and some Pollack fur instance, we don't nacherly amalgamate, and we can't never get along together."

"That goes, Jack, if you and the Pollack ain't human and ain't supposed to have brains. A lot o' trees grows up together, each one keepin' separate and tryin' to git higher'n the other. They can't do no other way if they want to. They can't move to give no saplin' a chance to grow and make the grove bigger. You gotta be a human bein' an have brains to take part of another guy's load when your own back's about broke, just cause you want to feel that you helped some guy out and that you had a hand in doin' somethin' worth while. You know all the time that the extra pay you're gonna git, is the better taste you git out of your pipe that night when you set and think it over and say, 'them transportation guys can't ride the old man tomorrow cause they didn't have cars enough, fur the barn's empty and I helped do it.' "

"They's a lot o' ginks all over the country quittin' their jobs an' claimin' the reason is because they kin git more money, when the facts is that they is dissatisfied where they're at just like you are, because they think all the givin' up has got to be done by the other feller and none by them. Son, they ain't no place where that's done reglar."

"Try this here amalgamatin' game awhile and you'll find out that the job you got and the gang in this here barn is better'n you kin find most places. They's a funny rule about this game, though, that you gotta allus remember or you lose. Its up to the guy that feels he's jest a little better'n another guy to lead first, every hand."

"Well, its ten minutes after, an she ain't blowed, so I guess the ol' man has picked out this here Sunday to amalgamate a little hisself".

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country.

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

JANUARY 1919

Railway Motor Testing—I

This subject is of such importance that it will be subdivided and treated under four main headings, as follows:

1—Testing apparatus.
2—Armature testing.
3—Field or frame testing.
4—Assembled motor testing.

TESTING APPARATUS

There are a number of different methods of testing railway apparatus. The most important of these will be considered by describing the general make up of the apparatus required, scheme of connections, current supply and the various tests that can be made by using this apparatus.

An Insulation Testing Box consists of a transformer, mounted in a case, fitted with a pilot lamp, line switch, circuit breaker or fuse, and dial switch to regulate the voltage as shown in Fig. 1.

Source of current—110 volt alternating-current circuit.
Uses— Test for grounds.
Test for insulation breakdowns.
Test commutators for short-circuits.

A Lighting-Out Line consists of a bank of five 110 volt lamps connected in series, mounted on a stand. One end of the lamp bank wire is connected to the trolley circuit, and the other end used as one of the terminals of the testing circuit. The other terminal of the testing circuit comes from the rail or ground connection, as shown in Fig. 4.

Source of current—500 volt, direct-current trolley circuit.
Uses— Test for grounds.
Test for open circuits.
Test commutators for short-circuit.

A Telephone Receiver Set consists of several dry cells connected in series with a small buzzer, with two terminals that are applied to the commutator surface a few bars apart, as shown in Fig. 5. A telephone receiver connected to two other terminals that are held on adjacent commutator bars is used to explore the coils located about midway between the terminals from the buzzer circuit.

Source of current—The batteries in the testing set.
Uses— Test wound armatures for short-circuits, for open coils, and for reversed or crossed coils.

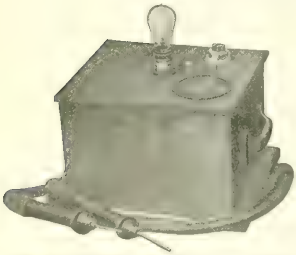


FIG. 1—PORTABLE BENCH TYPE TESTING OUTFIT

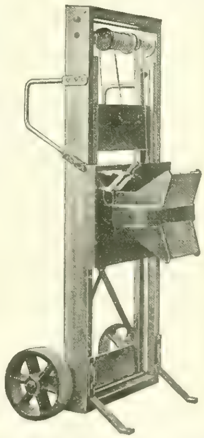


FIG. 2—PORTABLE ARMATURE TESTING YOKE

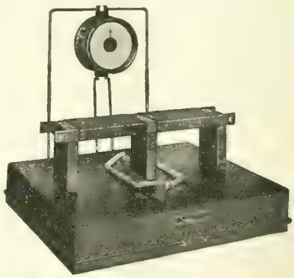


FIG. 3—COIL TESTING OUTFIT WITH WATTMETER

An Armature Testing Yoke consists of a laminated iron core with two straight sides set at an angle to better fit the surface of the armature core as shown in Fig. 2. Around this core is wound a coil of wire, (exciting coil), which is connected to the power line through a switch.

Source of current—110 volt alternating-current circuit.
Uses— Test wound armatures for short-circuits, open coils, and reversed or crossed coils.

A Coil Testing Outfit is made up of an E shaped laminated core with a detachable laminated yoke as shown in Fig. 3. A coil of wire (exciting coil) is wound on the middle leg of the core and two coils on the back of the E shaped core, one on each side of the middle leg. These two coils are alike and are connected in series to buck one another, so that under normal conditions, no current flows through them. A wattmeter or a telephone receiver is put in this circuit to detect any current that might flow, due to a magnetic unbalancing caused by a short circuit in the coil that is being tested.

Source of current—110 volt alternating-current circuit.
Uses— Test for short-circuit in coils.

As a substitute for the batteries, a small bell ringing transformer can be used where the primary coil (large number of turns) is connected to the 110 volt alternating-current lighting circuit and the secondary coil (small number of turns) is connected to the testing circuit to replace the batteries. In place of the bell ringing transformer a 110 volt alternating-current circuit direct through a lighting out line can be used as a source of power.

The "New Century" Tester is a special modification of the testing outfits shown in Figs. 5 and 7, with all the apparatus mounted in a self-contained box. When testing the fields, as shown in Fig. 6, the readings are obtained by sliding the pointer knob along the scale to a point where two distinctly separate sounds in the receiver become one, and from a table of values supplied with the outfit, the condition of the coil is determined. The armature test is a bar-to-bar test, using a telephone receiver and a contact fork.

Source of current—110 volt direct-current circuit.
Uses— Test field coils and armatures for short circuits, open circuits and grounds.

A Bar-to-Bar Set consists of variable resistance connected in series with an ammeter, a switch, a source of power and two terminals that are connected to the commutator approximately 90 degrees apart. A millivolt meter with the leads placed on two adjacent commutator bars, is used to explore the coils located about midway between the terminals from the ammeter circuit.

Source of current—500 volt direct-current trolley circuit.
Uses— Test wound armatures for short-circuits, open coils and reversed or crossed coils.

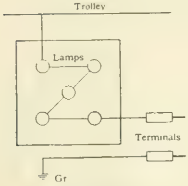


FIG. 4—LIGHTING OUT LINE

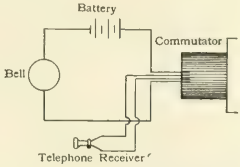


FIG. 5—TELEPHONE RECEIVER SET

Insulation Resistance—To check the insulation resistance of a motor, connect a high reading voltmeter in series with the machine or apparatus to be tested and connect leads to trolley and ground, as shown in Fig. 8. The insulation resistance is found by subtracting the meter reading through the insulation from the meter reading on the line direct and multiplying this

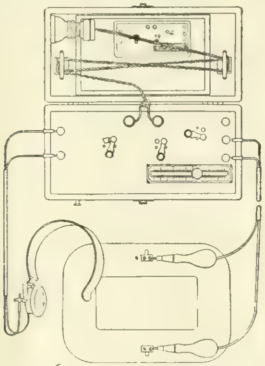


FIG. 6—NEW CENTURY TESTER

result by the resistance of the volt meter and then dividing by the meter reading through the resistance. This is shown in the form of an equation as follows:

$$R = \frac{r\,(d-d_1)}{d_1}$$

Where R = the insulation resistance
r = the resistance of voltmeter
d = the deflection of the meter on the line direct.
d_1 = the deflection of the meter with the insulation in series.

Source of current—500 volt direct-current trolley circuit.
Uses— Measure the insulation resistance of coils and of completely wound machines.

Polarity of Motor Field Coils—The apparatus for this test consists of a switch and one or more resistors connected in series with the trolley and the rail or ground with two terminals connected to the motor field coils assembled in the motor frame. When the switch is closed, the fields are tested for polarity by means of a compass needle, as shown in Fig. 9.

Source of current—500 volt direct-current trolley circuit.
Uses— Test the polarity of assembled field coils.

Testing Circuit to Run Motors—This consists of a controller in series with a group of grid resistors and a circuit

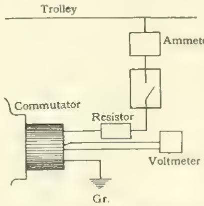


FIG. 7—BAR-TO-BAR TESTING SET

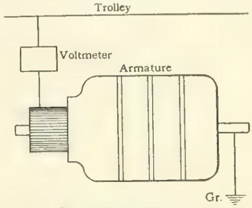


FIG. 8—CONNECTIONS FOR INSULATION RESISTANCE TEST

breaker, connected to the trolley circuit. Two terminals, one from the controller and the other from a rail or ground, are connected to the motor leads. A field and an armature lead are used for this connection, the other field and armature leads being connected together, as shown in Fig. 10.

Source of current—500 volt direct-current trolley circuit.
Uses— To give the motor a running test.

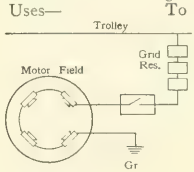


FIG. 9—CONNECTIONS FOR TESTING POLARITY OF FIELD COILS

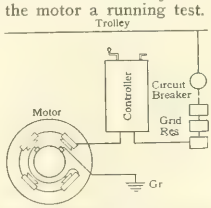


FIG. 10—TESTING CIRCUIT FOR OPERATION OF MOTOR

The methods of making tests on new or repaired coils, armatures or motors by means of the testing outfits described above will be given in succeeding R. O. D. J. S. DEAN

THE JOURNAL QUESTION BOX

OUR subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. The topics should be of general interest; information involving the specific design of individual pieces of apparatus is not supplied. Care should be used to include all data necessary for an intelligent answer.

A PERSONAL reply is mailed to each questioner enclosing a stamped, self addressed envelope as soon as the necessary information can be obtained. Anonymous questions cannot be considered. As each question is answered by an expert on the subject involved, and checked by at least two others, a reasonable length of time should be allowed before expecting an answer.

1686—INDUCTION MOTOR SECONDARY DATA—When one inquires of a motor manufacturer for rotor data of a slip ring type induction motor for use in the choice of a controller, do the volt and ampere values furnished represent the amperes flowing through each ring, the voltage being read across each pair of rings and the rotor blocked while full voltage is being impressed across the primary or stator windings? Compare the relative performance of three five hp, three-phase, 60 cycle, 220 volt slip-ring type motors having rotor data as follows:

R.P.M.	Volts	Amperes
1200	105	23
900	55	45
900	?	17.5

F.G.F. (OHIO)

The voltage given is the voltage between slip rings with the motor at stand still and secondary leads open. The amperes given are per ring with the motor operating under full load, the frequency and voltage being normal. Motors of the same horse-power rating, type and speed from the same manufacturer should have the same secondary data, but it will be different for motors of different speeds, types and different manufacturers, although the horse-power rating is the same. This is because the secondary voltage depends on the transformer ratio between the primary and secondary, which is dependent on the slot combinations and windings which, of course, will not work out the same in every case and condition

on a given horse-power rating. The product of the secondary volts and secondary amperes will, of course, be approximately the same in every case for motors of the same horse-power rating.
B.B.R.

1687—PROTECTION OF MILL MOTOR FROM DIRT—In my care I have a three-phase, 60 cycle, 440 volt, 720 r.p.m. induction motor located in a drop forge plant where dust, smoke and hot scale from the forgings get into the motor. Fig. (a) shows a proposed hood and piping fitted to the journal brackets of the motor and an eight inch pipe connected to a four inch pipe leading to each hood, the eight inch pipe to extend out doors and carried down to a point lower than the motor, the idea being to create a draft and by the aid of the fans on the rotor to force air out through the ventilating ducts in the motor. Please let me know if this scheme will be satisfactory. R.J.B. (MICH.)

Motors that are designed to be self-ventilating depend on having an abundance of free air available, and will not draw in sufficient air to properly cool themselves if much resistance is offered, such as might be occasioned by a pipe, especially if it has many sharp turns. The pipe should, therefore, be extremely liberal in size, and as short and straight

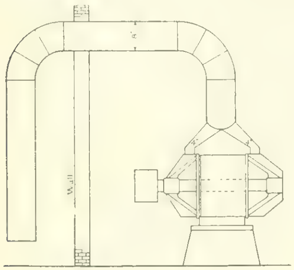


FIG. 1687(a)

as possible. The pipe should have a cross-section such that the velocity of the air entering the motor will not exceed 750 feet per minute when the required amount of air is passing through. The amount of air required depends on the size and design of the motor, but about eight cubic feet per minute per rated horse-power of the motor will generally be found satisfactory. If a blower is used to force air into the motor, velocities in the duct of from 1500 to 2000 feet per minute can be used. We suggest bringing the air in along the floor as shown in the Sept. 1918 issue of the JOURNAL, p. 334, Fig. 2. This will make the pipe much shorter and eliminate some of the turns. The air should be allowed to escape through a hole in the frame, if available, or through openings in the top of the enclosing cover opposite to the intake. The hood for each end of the motor should be designed split horizontally, and arranged so the top half can be readily lifted off for bearing inspection, etc. The air duct in Fig. (a) has 25 square inch area, where it enters the motor, this is 0.173 square feet. 0.173×750 (ft. per min.) $= 130$ cu. ft. of air per min. $130 \div 8 = 16.25$. This piping would be large enough for only a 16.25 hp motor. O.N. (S.C.)

1688—CHANGING TRANSFORMER FREQUENCY—It is desired to make new transformers for 50 cycle operation out of 125 cycle transformers which, due to the heavy losses and undue heating, are at the present time useless. It has been suggested that the section of the core could be doubled, that is, make a new winding on a core formed by the juxtaposition of two of the existing cores, this winding keeping the same number of turns both primary and secondary.
A.U. (MEXICO)

Reasonably satisfactory operation can be secured by taking two transformers of the same size and connecting both primary and secondary windings in series thereby impressing approximately one half normal voltage across each transformer. If the secondaries are arranged for series-parallel connection for 110 and 220 volts and, it is desired to secure 110 volts, it is best to use the series connection and connect the secondaries of the two transformers in parallel. This will place the same voltage across each transformer which will not be exactly the case if both primary and secondary windings are in series across the line. It will not be satisfactory to take two transformers differing in size and connect both primary and secondary windings in series across the line nor is it generally advisable to connect two transformers of different makes or different types in this way. If it is desired to rewind the transformers, probably the best thing to do is to double the number of turns, using smaller wire, of course, without any change in the core and reduce the rating to one half or probably something less than one half of the original 125 cycle rating. The scheme of doubling the core and using the same number of turns can be used if desired. W.M.M.

1689—TRANSFORMER CONNECTIONS — In our present distribution system four separate voltages are employed 2300, 6600, 13 200 and 22 000. In order to simplify the system it is desired to reduce these to two, 2300 and 13 200, as the latter is entirely adequate for present and prospective needs. We would like to continue in use, if possible, a bank of three 250 k.v.a., 6600 to 22 000 volt transformers. This bank is connected delta-delta, and the high tension windings of each transformer are provided with taps for 22 000, 21 000, 20 700 and 20 000 volts, while the complete low-tension winding has connections for 6600, and lower voltages. It has occurred to us that if a middle tap can be secured in the low-tension windings and the two halves connected permanently in parallel, that with 2200 volts impressed on the low side, we should get approximately 13 200 volts from the original taps for 20 000 volts on the high-tension side. The transformer would then work at two thirds of its normal voltage rating. We presume that its k.v.a., capacity would likewise be reduced by one third of its former rating; that is, it would be unsafe to increase the current above the old rating. We would like your advice as to whether the scheme is feasible and whether the transformer losses will be increased or not.
J.B.W. (Texas).

If the low voltage winding can be divided into two equal parts, they can probably be connected in parallel and operated satisfactorily in this way. If 2200 volts is then applied, the 20 000 volt tap in the high voltage winding will give approximately 13 200 volts. With the transformer operating at only two thirds normal voltage, the iron loss will probably be reduced more than 50 percent, so that, at the reduced voltage, the transformer will probably carry from 75 to 80 percent of the k.v.a., output that it would carry at full normal voltage without any increase in temperature rise. W.M.M.

1690—INDUCTION MOTOR SECONDARY—I would like your comments on a change I have made in a 75 hp., three-phase, 60 cycle, 10 pole, 720 r.p.m. motor of the internal resistance starting type. The stator is connected two circuit delta and has 120 coils wound with six turns of No. 9 D. C. C., wire in each coil. The rotor has 90 slots with four conductors per slot. Each conductor measures about 3/16 by 7/16 in. I cut the rotor windings so that all the conductors run straight out from the core like a squirrel-cage motor, and short-circuited the bars with six strips of hard drawn copper 3/16 by 2 inches, riveted and soldered on each end, making 12 strips in all. At first after making this change the motor would not start the load but I cut part way through the rings at evenly divided points on each side of the rotor and now the motor starts fairly well. At no load it runs from 720 to 736 r.p.m. At about 70 hp., it runs from 710 to 720. The frequency is a little high but does not change often. The motor formerly ran at 680 r.p.m. at full load. Am I right in assuming that the motor is just as efficient now as it was before the change was made? Does this change affect the power-factor when this motor is pulling about 75 hp.? Will this motor pull a greater over load than formerly?
C.M.L. (Utah).

(a) The motor is actually a little more efficient than it was formerly. If it now runs at 710 r.p.m., at full load and formerly ran at 680, the copper loss in the rotor is now only 68/71 of what it was, and the new efficiency for the complete motor will be 71/68 of its former value. This is obtained directly from the fact that the motor efficiency equals the primary efficiency multiplied by the secondary efficiency. Then if E_1 equals the efficiency at torque T and slip S_1, and E_2 equals the motor efficiency at torque T and slip S_2 then $E_2 = E_1 \frac{(1 - S_1)}{(1 - S_2)}$ Based on a synchronous speed of 720 r.p.m. the efficiency has actually been increased about 4.2 percent. With such a low slip i.e., only 10 r.p.m., in 720, you might expect low starting torque, as you actually found to be the case, and the applied remedy was proper, provided you did not reduce the ring section below the point required by mechanical considerations. (b) There would be a small improvement in the power-factor due to the fact that the leakage reactance of a squirrel-cage winding is somewhat less than that for a corresponding phase winding. A reduction in the leakage reactance means a reduction in the wattless component of the current and hence a slight gain in the power factor. (c) The maximum torque or pull out would

also be increased a small amount for the same reason as that cited under (b).
A.M.D.

1691—CHANGING A THREE-PHASE GENERATOR TO SINGLE PHASE—I recently changed a 30 kw, three-phase, 60 cycle, 1200 r.p.m., 2300 volts, 7.5 amperes per terminal revolving field alternator over to a single-phase generator of the same voltage, hoping to be able to get 30 kw from it. It had a 72 slot stator of 36 coils which spanned 1 to 10 slots and it was connected two coils per pole per phase, all poles in series-star and the owner of the machine wanted me to connect it so as to use all of the coils in the winding. I first connected it up six coils per pole in series and three poles in parallel two in series, but as the voltage only built up to about 800 volts, I then tried a three pole series, two pole parallel connection and as it then only built up to about 1600 volts, I changed it to all poles in series which caused it to give a range of voltage from 2100 to 3000 which was about the same as it had been doing on the three phase connection and with the load applied the regulation seemed to be a little better than it had been before changing over from three phase. But what I cannot understand is why I had to connect this stator with all poles and coils in series to get 2300 volts, as it looked to me at first that with all coils and all poles in series as a single-phase generator, the voltage

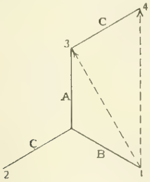
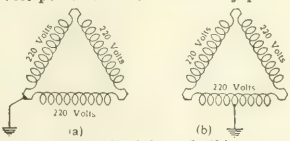


FIG. 1691(a)

should be 7200, as I found it connected two coils per pole per phase with all poles in series. It looked to me as if each coil had been generating 200 volts so that is why I first tried a three-pole-parallel two-series connection as I thought that would give me the voltage of two poles or 12 coils. Can it be that the span of 1 to 10 slots of the coils have anything to do with the way this machine acted on the three-pole-parallel, two-pole-series connection with six series coils per pole? Would it have acted better on any pole grouping or connecting if I had made it only five coils in series per pole thereby having six idle coils in the winding? Can you tell me if this machine will develop 30 kw at 2300 volts the way I now have it connected? Why did the voltage generated in each coil change from 200 to about 83 after connecting all poles in series with six coils in series per pole? Would it have been better to have left it a three phase connection and continued to carry a single-phase load?
F.D.H. (IND.)

The principal source of error is in the assumption that the terminal voltage of the machine divided by the number of coils in series equals the voltage generated by each coil. The voltages of the coils are out of phase and must be added *vectorially.* Fig. (a) shows the machine as connected for 2300 volts three-phase star and for single phase all coils in series, as made by connecting phase C to the outer end of phase *A*. The voltage per phase is 2300 ÷ 1.732 volts. If the drawing is made to scale so that *A*, *B* and *C* represent the phase voltages 120 degrees apart, then the three-phase voltage is indicated by the length of 1—3 and the single-phase voltage by 1—4, which is 2660 volts. The chording does not affect the change and if only five coils per poles were used, the voltage would be somewhat less. No other pole grouping would improve the results providing the same number of coils are connected in series. The rating of the machine as three-phase is 1.732 times the terminal voltage times the amperes per terminal or 1.732 times 2300 times 7.5 = 30 k.v.a. As a single-phase machine with all coils in series the rating is voltage times amperes or 2300 times 7.5 = 17 k.v.a. The single-phase rating may be increased somewhat for the same armature heating, because of the smaller iron loss. With the machine connected three-phase and loaded single-phase the rating would be 17 k.v.a., at 2300 volts, but this may be increased to about 20 k.v.a., because the idle portion of the armature aids in the dissipation of the heat from the active winding. There is, therefore, nothing to be gained by making the change from three phase to single phase in such cases.
C.R.C.

1692—GROUNDING A DELTA CONNECTED TRANSFORMER BANK—In grounding the secondary of a three-phase delta-connected bank of transformers for 220 volt power service is there any prefer-



FIGS. 1692(a) and (b)

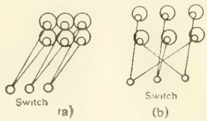
ence in grounding one corner of the delta or grounding the neutral of one transformer?
W.S.G. (N.J.)

It matters little whether one corner of the delta or the middle of one side is grounded. Possibly slight preference might be given to the latter point since it is a little nearer the neutral point.
W.M.M.

1693—INDUCTION MOTOR WINDING—I have a 15 hp, three-phase, four pole, 440 volt, 18.8 amperes, 710 r.p.m. star connected induction motor having a one circuit winding with five coils per group and 60 coils total. The stator coils are wound with nine turns of No. 12 square wire. I would like to rewind this motor with round wire, for which there is plenty of room in the slots. Would No. 11 round wire do, using one more turn per coil, or what size would you recommend?
A.D. (Mo.)

If No. 12 square wire was O. K., No. 11 round will be all right. This copper section however, seems a trifle small for 18.8 amperes. If there is room for No. 10 round it would be still better. Do not change the number of turns. Use nine turns, the same as with square wire.
A.M.D.

1694—DISPOSITION OF CONDUCTORS—Reading question 1594 brings me up with a jerk to the fact that we are just installing some work of almost like character and I make haste to ask if we will experience the same trouble. As shown in Fig. (a) 750 000 circ. mil lead covered cables to carry about 750 amperes each at 440 volts are installed in three inch fibre ducts about 75 feet long. The conductors are spaced about four inches apart. (a) Is our grouping of conductors correct? (b) Should the lead sheathings be insulated from each other or connected together at the ends? (c) These con-



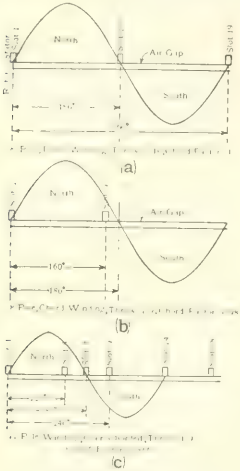
FIGS. 1694(a) and (b)

ductors are brought to the switch through two feet lengths of iron pipe supports. In that regard what is the effect of running single conductors through iron?
F.T.S. (Calif.)

The cable grouping shown in Fig. (a) should not cause an unequal division of current between the two parallel cables of each phase, for in any phase the magnetic relation of the upper cable with respect to the remaining ones is identical with that of the corresponding lower cable with respect to the others. However, with this arrangement the current will not necessarily distribute uniformly over the cross-section of the conductors. A more uniform distribution of the current over the cross-section of the conductors should be obtained if the cables were rearranged so as to more nearly approach the symmetrical three-phase arrangement. Such an arrangement is suggested in Fig. (b), using the same duct arrangement as given in Fig. (a). (b) The lead sheathings of all of the cables should be bonded together at one point and grounded in order to protect against static and breakdown discharges. But the remaining portion of the lead sheathings of the cables of each phase should be insulated so as to avoid a closed circuit in which secondary currents can circulate. (c) When a single conductor in an iron pipe carries current, the amount of flux interlinking the conductor throughout the pipe length is greatly increased on account of the high permeability of the iron. If the conductor carries alternating current, the rapid reversal of the flux produces a hysteresis and eddy current loss which is dissipated in the iron and consequently raises its temperature. With large values of current, the temperature of the iron may become so high as to greatly increase the fire hazard. For this reason, it is usually not considered safe practice to run single alternating-current conductors or cables through iron pipe.
C.M.L.

1695—RECONNECTING INDUCTION MOTORS—In the February 1916 issue of the Journal is an article on "Reconnecting Induction Motors" in which the subject is pretty generally covered. I have however been unable to determine what might be called a limitation in one direction, namely the effect of coil pitch on a pole changing reconnection, and would appreciate greatly an expression of opinion. As a hypothetical case take a motor having 72 slots and coils, connected for eight poles which it is desired to slow down. The motor is wound for 220 volts, 60 cycles, three phase. Obviously the motor will afford a symmetrical coil arrangement if reconnected for 12 poles, and the question at

issue is the effect of the coil throw on the reconnected motor. The present coils lie in slots 1 and 9. In one case under consideration the reduction in output due to the reduced speed is offset by the reduced requirements of



FIGS. 1695(a), (b) and (c)

the machine operated and in an emergency some considerable drop in both efficiency and power-factor would be permissible as the load factor is small. This question has been argued at some length among local men and an authoritative expression of opinion would be of considerable interest.

H.B.B. (Colo.)

The effect of changing the coil pitch is explained in the article referred to in the Feb. 1916 Journal under the heading "Chord Factor". This is explained graphically in Figs. (a), (b) and (c). Fig. (a) shows a cross-section of a motor rolled out flat showing the clearance or air-gap between stator and rotor and showing by the shaded area under the sine curve a pair of magnetic poles. A 72 slot, eight pole combination is assumed, which means that if the coils are exactly "pitch", any individual coil will be in slots 1 and 10 and the distance measured between the centers of slots 1 and 10 represents 180 electrical degrees, because the distance from a point on one north pole to the corresponding point on the next adjacent north pole is 360 degrees or a complete magnetic circle. If the coil were wound in some other slot, as for example 1 and 9 as shown in Fig. (b) if the cross connections were still left for eight poles, the magnetic field would still be nine slots in width because $\frac{72 \text{ slots}}{8 \text{ poles}} = 9$ Changing the coil pitch then does not change the number of poles nor does it change the pole arc as measured around the stator, but it does have the effect of changing the shape and size of the shaded area representing the magnetic field and by so doing affects the performance and output of the motor. Expressed in another way it affects the magnetic and electric effect of each conductor so that instead of being equivalent to a whole conductor it is only equivalent to a fraction of a conductor. This measure of the effectiveness of the conductor is expressed by the sine of one-half of the electrical angle spanned by the coil. For example in Fig. (a) the coil spans 180 electrical degrees. The sine of one-half of 180 = 90 degrees is 1.00 hence the conductor has its maximum magnetic and electric effect. In Fig. (b) the coil spans 160 degrees and the sine of 80 degrees = 0.98, hence the conductor is only 98 percent as effective as if the coil were wound in slots 1 and 10. If the coil lay in slots 1 and 8 it would span 140 electrical degrees and the sine of 70 degrees = 0.936 so the conductor has 93.6 percent of its maximum effect. If the coil lay in slots 1 and 7 it would span 120 degrees and its effect would be sine of 60 degrees = 0.866 or 866 percent of its pitch value. Passing to the 12 pole connection shown in Fig. (c), 180 electrical degrees is now measured by span of 72 ÷ 12 = 6 slots. Since the coil is wound in slots 1 and 9 it is over pitch and the effect is the same as under pitch and measured in the same way. If 1 and 7 is 180 degrees, 1 and 9 is 240 degrees and the sine of 120 degrees is 0.866 or the coil has the same effect as if wound in slots 1 and 5. The maximum chording usually attempted in practice is one half or 90 degrees and the chord factor = sine of 45 =0.707. If the coil is wound any smaller pitch than 90 degrees, disturbances of the magnetic conditions become serious and nothing is gained by further chording. The value "sine of one-half the electrical angle spanned by the coil" is referred to by designing engineers as the "chord factor" and is discussed as such in the Journal article referred to.

A.M.D.

THE ELECTRIC JOURNAL

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A Central Station Opportunity

Electricity is one of the master keys to the future health and prosperity of the United States, and its field of use will undoubtedly extend beyond any limits which can now be foreseen. Within the life time of living children the population of the United States may reach 250 000 000. The problem of supporting such rapidly increasing numbers in health and comfort, while at the same time maintaining our high standard of living, would have been presented in any event for solution very soon, but the war has brought it forward for consideration now.

No one should delude himself into thinking that the pre-war conditions of *laissez faire* will ever return. For those who have regarded it as right to conduct their business affairs as they pleased and have thought that the automatic checks and balance of profit and loss would preserve all community interests, it may be somewhat of a wrench to come to the realization that we have, in fact, no right to do anything which means an economic waste of natural resources, or of man power.

It is trite to say that the United States is the most wasteful country in the world, but now for the first time we have had a reminder that conservation is really a matter of individual interest. The coal shortage of last winter was a great object lesson to the whole people, and caused sufficient inconvenience to show clearly what serious results would happen if there were twice the population and half the existing coal supply.

The railroad facilities of the country are now uncomfortably inadequate, and moreover the increasing demands of a complicated distribution system in a country so large and wealthy as the United States will shortly require great improvements and extensions in transportation service. The requirements of the population for food and clothing will demand a more intensive and economic cultivation of the soil and an almost universal use of fertilizer to maintain its productivity. The growth of hundreds of our cities will require more transportation facilities and other public utilities, and so on through an indefinite list. The only known force which can perform this work economically, and it must be performed in order to support the population of the future, is electricity.

Electrical apparatus can no longer be said to be in its infancy so far as its development is concerned, for generating machinery, motors, illuminating devices, in fact all electrical equipment has reached that point of technical development where its operation is surer and less subject to accidental interruptions and shut-downs than any other machinery. Its operation and construction are simplicity itself. It is generally foolproof in its operation and is, therefore, capable of performing good work in inexperienced hands. This is no small factor in the rapid expansion of its field of usefulness.

It is capable of furnishing power in the largest units. On the other hand, tiny motors performing the lightest service are useful machines and not toys. In brief, there is a breadth and flexibility of service which is possible in no other form of energy. It can provide a variety of service generally comprised by the terms—light, heat and power—from a single machine. In short, it is beyond doubt that the standard power for the future is to be electricity.

Within a comparatively few years electric power will undoubtedly force its way into general use on steam railroads. This cannot be avoided because, quite aside from the admitted economies of operation, it is estimated that the complete electrification of the lines of a busy railroad system doubles its capacity. In other words, it has the same effect as if a single road were double tracked. In no other way can the railroads increase their carrying capacity largely at so little cost.

The production of fertilizer for the future involves processes which demand large volumes of electrical power, and this demand will be just as unavoidable as the demands of steam railroads. A more intensive system of farming and the necessity of saving man power on the farm, due to the natural inclination of people to congregate in large cities, will require the extensive use of electric energy; in fact, the development in this field is already remarkable; but the surface has been, of course, but scratched.

Regardless of the present unfavorable financial condition of the traction systems in our large cities, the people must have transportation, and more of it, and there is no satisfactory substitute for the electric operation of the cars. If one goes on through the entire list of activities of a complicated industrial community, it will be found that electricity has become a necessity of prime importance.

While this field is just beginning to open, there are a few facts which indicate that there is a question at issue for the consideration of the leaders in the central station field, viz., whether that industry as a whole is satisfied with the outlook of the present methods of supplying this universal necessity to the people. I know that some of the notable leaders have been looking into the future with far-seeing eyes, and perhaps all central station men do; but, nevertheless, it would seem wise at this time for the responsible men connected with the industry to review the whole situation and see if they are in line with the progress of events.

On account of the shortage of power in a few manufacturing centers in the East last winter the United States Government made a survey of certain sections and it developed that in most of them there was a tremendous waste of fuel due to small detached power companies with poor load factors and inefficient power stations. Calculations were made as to the savings

which would have been effected in some of these areas by linking all the companies into one system and operating it as a unit. Some of these figures were astonishing, and the results of this investigation have aroused in Washington considerable interest which is not likely to die out with the war.

This data will be at the disposal of the Government and will undoubtedly be considered in the future when applications are made for Federal permission to develop water powers. It is entirely probable that Federal permits will not be granted without taking into consideration the entire question of the economic distribution of power within the area reached by the proposed development.

By a succession of easy steps it is possible and even probable that the Federal Government will regard the development of all power systems as charged with new public interest, particularly in the populous sections of the country; to the end that economic waste may be prevented as far as possible. Therefore, it would seem that the present offers an opportunity, which may never come again, for the leaders in the central station field to consider comprehensively the situation within the natural geographical areas in which they operate, and to use their great power and ability to secure enabling State and Federal legislation which will permit the re-arrangement, consolidation and extensions of their power service so that it can be dealt with as one reservoir from which all the needs of the section can be served.

It is evident that sympathetic support would be given to such a movement by the Federal Authorities, and that now is the time to act in order that in the future it may not be said that private ownership was incapable of meeting the situation. GUY E. TRIPP

The S. A. T. C.

The passage of the "Man Power" act in August 1918, reducing the draft age to eighteen, threatened the existence of every educational institution. If the War Department had not invited the schools to co-operate in a plan for training soldiers, they would have had to close their doors.

The collegiate section of the Student Army Training Corps (Section A) did not offer an ideal educational programme. Its main object was to meet an emergency demand for officer material. A complete engineering course could not be attempted, but certain men who demonstrated special ability could make very satisfactory progress in the study of fundamentals even in a short time. In short the whole plan should be considered as a device for first sorting men according to their native abilities, and then giving such special training as the time available permitted. In this, as well as all war activities, both men and institutions served where they were most needed and not where they might have chosen. It was not a matter of getting every man in his right place but of getting every place filled by its right man.

While the Army had need for men skilled in certain specific lines, yet the one characteristic desired by all branches of the service, was that of resourcefulness—an ability to apply a knowledge of fundamental principles to the materials at hand and under the worst of conditions. Very rarely were standard materials and tools available at the Front. Hence, the training period being very short, all details of specific application were eliminated and full attention was concentrated upon fundamentals.

While such a short intensive program interferes in many ways with a complete engineering training suited to peace times, yet it does have the advantage of developing those personal characteristics which enable men to meet emergencies. Most of the special jobs in the Army required a knowledge of only the very simplest fundamental principles and a great deal of ingenuity in application. The work of the vocational section was not intended to develop engineers; and yet throughout the one hundred and fifty-five schools having National Army Training Detachments, (SATC Section B) there was universal astonishment at the accomplishment of untrained men in the understanding and application of the fundamentals of such technical subjects as gas engine performance, radio and telephone electrical work, etc.

Educationally the S. A. T. C. should be regarded entirely as an experiment. In its short existence (Oct. 1, to Nov. 11) and in spite of the "Flu," shortly followed by the armistice, and the tremendous disturbance created in standard engineering school programs, certain things point toward real progress along the lines that all engineering teachers have been thinking and hoping for the past few years. In the coming re-adjustment of engineering curricula throughout the schools, more time will be given to fundamental principles and less to the details of application; more attention will be given to developing those personal characteristics which make for man-power rather than storing the mind with engineering data and, most important of all, more attention will be given to the initial sorting of men and the direction of their training according to their several native abilities rather than their ill-considered desires. It is a fortunate coincidence that the Mann report on engineering education should have come out just at this time with its wealth of helpful constructive suggestions.

Over five hundred American Colleges and Universities gave their all to the cause of the war and in thirty days became little army camps for training real American soldiers, only a part of which training was mathematics, chemistry, or physics. If nothing more is accomplished than to dislodge some of the old standard traditions, and speed up the machinery for putting into force these new ideals of education (which incidentally are as old as Socrates) the S. A. T. C. will have been an educational success. C. R. DOOLEY

Performance of Motor-Generator Sets

For the Chicago, Milwaukee & St. Paul Railway

F. T. HAGUE

SERVICE REQUIREMENTS of generators in high-voltage, direct-current railway operation are not essentially different in theory from those in the usual low voltage electrifications, except that certain operating characteristics, such as flashing on severe overloads, heretofore usually considered inherent in all commutating machinery, change from the category of relatively harmless operating difficulties on low-voltage machines, to positive liabilities in the case of machines built for higher voltages. The concentration of large powers at high voltage in a single generating unit emphasizes the necessity of protecting a machine against itself by materially improving its commutating performance, and necessitates a revision of the standards of satisfactory operating characteristics which have heretofore been commercially acceptable on low-voltage installations.

DIRECT-CURRENT generators have been used as the source of power supply to railway systems for more than 30 years, and during this period have undergone a continuous development, tending towards improvement in performance. The early introduction of commutating poles and the later development of commercial forms of compensating-pole face windings are now landmarks in the evolution of commutating machinery, and form the basis of all further improvements which tend to place railway generators on the same high plane of reliability as other forms of commercial electrical apparatus. Recent improvements in railway generators have been in the direction of increasing the momentary overload commutating capacity so as to enable a machine to withstand the overloads and short-circuits which are incident to this severe class of service. This improvement has been brought about by the consistent development, to a very high plane of efficiency, of all the component parts of generator construction, and particularly by the use of a type of magnetic circuit construction which allows the commutating pole's effectiveness to be maintained at loads well up to the short-circuit value.

It is not possible theoretically, however, to obtain the same margin of momentary commutating capacity on machines of all ratings at 3000 volts, because of certain fundamental mechanical limitations (such as safe commutator speed and distance between brush arms) which handicap machines of less than 750 kw rating when run at the speeds which are standard on moderate voltage machines. This is a fortunate circumstance in that, for this special class of service, machines of approximately 1000 kw at 1500 volts are of about the ideal capacity on which to obtain the maximum commutating performance. The recent development of a 3000 volt unit of 2000 kw capacity (two 1500 volt generators in series) which will carry momentary loads of 10 to 12 times normal, without showing distress at the commutator, and which will deliver 20 times full-load current on dead short-circuit without "bucking over", marks a considerable advance in the reliability of operation of high voltage railway generators. The performance of this unit is to be viewed more as an example of the results which are possible on a special high-voltage unit when all conditions of rating, speed and voltage combine to give the most favorable combination, rather than as a criterion for other sizes and types of high-voltage machines which do not have as great theoretical commutating possibilities.

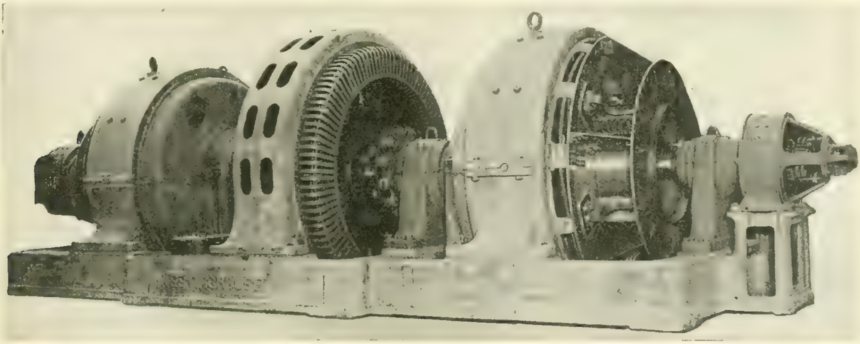

FIG. 1 TWO THOUSAND KW, 3000 VOLT SYNCHRONOUS MOTOR-GENERATOR SET

However, in order to give high-voltage machines these enormous momentary commutating capacities, it is necessary to adopt very conservative designs, in which the best known devices for the improvement of commutation are carried far toward their limits, thus necessitating greater refinements in construction and consequently higher costs. This means, in general, that a machine must be run at a relatively low speed, considering its capacity; that its magnetic circuits must be so generously proportioned as to be free from the detrimental limitations of saturation, even at the most severe overloads encountered, and that the selection of the number of poles and the distribution of the armature

windings, etc., must be such as to produce the most favorable electrical combinations. In other words, many desirable commercial considerations must be subordinated to abnormal performance. It is thus theoretically and practically possible for high-voltage direct-

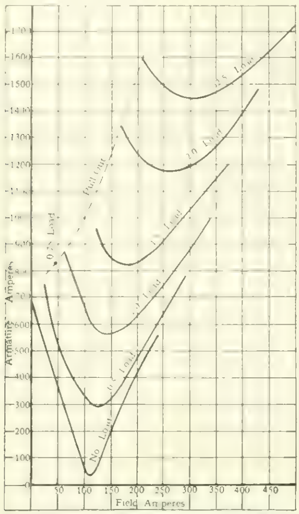

FIG. 2—V CURVES OF SYNCHRONOUS MOTOR

current machines to be given very creditable overload commutating characteristics, provided one is willing to pay the cost of incorporating these features in a special machine.

The performance characteristics of the 2000 kw, 3000 volt, 514 r.p.m. generators, built for the Chicago, Milwaukee & St. Paul Ry., give an indication of the commutating performance of a 3000 volt unit in which very conservative electrical and mechanical design limits have been adhered to. These motor-generator

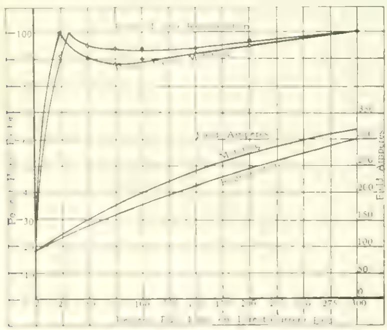
FIG. 3—[illegible] CURVES OF SYNCHRONOUS MOTOR
The current is lagging below 25 percent load and leading above this value, the transition from lagging to leading producing the sharp bend in the curves.

sets, shown in Fig. 1, consist of duplicate 1500 volt generators, connected in series to form a 3000 volt unit, and have two direct-connected exciters, the larger one supplying excitation to the synchronous motor, and the other excitation to the generators. The primary consideration was a construction which would withstand the electrical and mechanical shocks incident to carrying the extreme overloads which are met in railway service. Three thousand volt service has also presented new problems from the insulation standpoint, particularly in the methods of insulating the exposed commutator surfaces, and has necessitated the development of

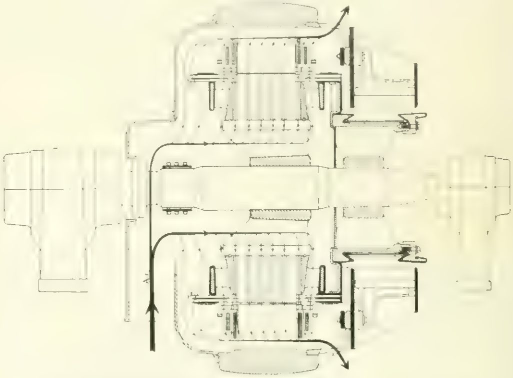
FIG. 4—CROSS-SECTION THROUGH DIRECT CURRENT GENERATOR
Showing radial ventilation system.

insulation methods considerably more elaborate than those found on lower voltage machines, in order to maintain the same generous electrical as mechanical factor of safety. The service requirement to be met, the distinguishing features of the type of construction employed, and the test characteristics of the set may be summarized as follows:—

CAPACITY

This set has a normal capacity of 2000 kw, 3000 volts, at 90 percent power-factor, and will carry 3000

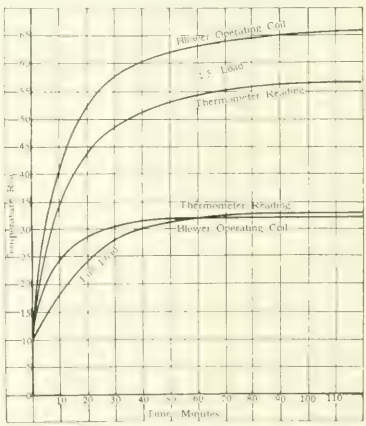

FIG. 5—TEMPERATURE CURVES AT FULL LOAD AND 1.5 LOAD WITH BLOWER

kw for two hours, with a temperature rise not exceeding 55 degrees C. The sets are to operate either direct or inverted (i.e. regenerative or braking) at loads up to 6000 kw for five minutes without injury, with the motor power-factor automatically maintained between

unity and 90 percent leading from half load up to 300 percent load. This heavy overload necessitates special provisions to increase the motor field excitation in order that the motor may have a generous margin of overload torque even when the line voltage drops to 85 percent

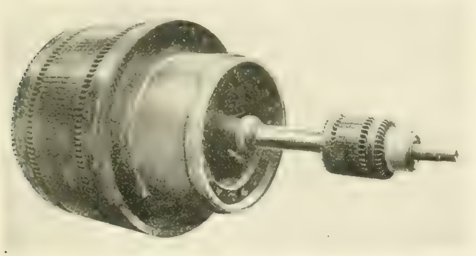

FIG. 6—ARMATURE OF GENERATOR AND EXCITER

normal. It is a characteristic of synchronous motors that the pull-out torque is roughly proportional to the excitation, and inversely proportional to the applied voltage, as indicated by the minimum excitation required for a given load, shown in the motor V-curves, Fig. 2. This overload requirement necessitates a compounding of the motor exciter, such that the motor field excitation automatically increases with the load, in the proper proportion to maintain the specified power-factor. The power-factor adjustment actually obtained is indicated in Fig. 3, which shows that the motoring and regenerative power-factor characteristic are practically identical, and that unity power-factor is reached at about one-half load, and a leading power-factor, varying between unity and 90 percent leading, is obtained up to 300 percent load. As some of the sets may require adjustment of the power-factor characteristic when operating at different parts of the electrified system, it has been arranged to vary this adjustment in a convenient manner by the use of an additional field winding, which is only used when a power-factor adjustment different from the factory setting, is required.

VENTILATION

The generators of this set are of the enclosed type, and are arranged for automatically-controlled forced ventilation at times of heavy overload. This arrangement minimizes the running light losses, by reducing

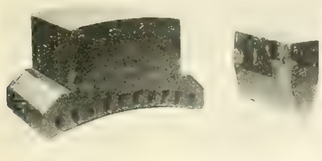

FIG. 7—MAIN AND COMMUTATING POLES

the machine's windage losses to a minimum during the long periods of light loads, which are inherent to this class of service and during which no forced ventilation is required. This saving of blower losses has been made possible by devising a thermal control system, which automatically starts the blower when the temperature of the direct-current armature winding reaches a limiting value of 75 degree C. The inherent difficulty of any system of armature temperature control is the obvious impossibility of obtaining any direct-reading temperature indicating device. It has been proven possible, however, to very closely approximate the observable thermometer temperature of the armature winding by means of the change in resistance of a small resistance coil mounted on a specially-proportioned and insulated current-carrying conductor in the stator windings. The thermal control system is so arranged that the rise in resistance of this coil actuates a relay, which starts the blower when the armature winding reaches an actual temperature of 75 degrees C. By basing the starting of the blower on the actual temperature of the machine, full advantage is taken of the low ambient temperature in which these machines operate for many months of the year.

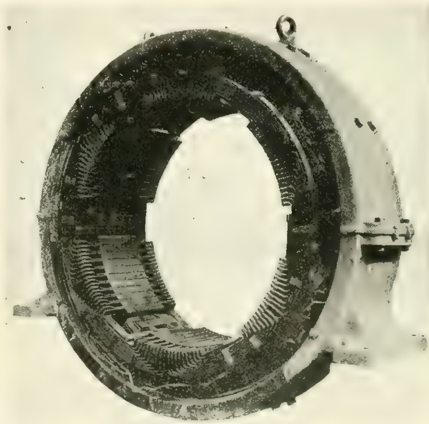

FIG. 8—GENERATOR STATOR CONSTRUCTION

The passage of ventilating air through the machine is arranged according to the radial system, shown in Fig. 4, in which the air is delivered to the inner periphery of the rotor by a double rear end bell, and is passed through radial ventilating ducts in the rotor core and around the under surfaces of the armature windings, and passes out between the field coils to the front of the machine. The core ducts are small blowers in themselves, thus giving the radially-ventilated machine an inherent ventilating force, tending to direct what air is available through the hottest part of the machine, and has a considerable power for pulling air through the core when the blower is stationary. Thus when running without an external blower, a radially-ventilated machine has a very generous continuous rating: possibly from 30 to 50 percent greater than the same machine would have with axial ventilation. The radial ventilation thus provides a very considerable inherent thermal margin of safety in normal operation, and, since the reliability of any thermal control system can never be

ideal, the use of radial ventilation assures a freedom from trouble in case of blower failure that is a vital factor in maintaining continuity of service.

TEMPERATURE PERFORMANCE

The thermal characteristics of this set are extremely liberal, as it can carry all of its guaranteed loads without the aid of forced ventilation, and still not exceed a temperature rise of 60 degrees C. This is made possible by the use of radial ventilation and the open armature construction shown in Fig. 6, in which the end windings are arch-bound on themselves circumferentially, and heavily banded down on an insulated coil support. The top and bottom of the coils in the end windings are thus exposed to the ventilating air, resulting in a ready dissipation of the end winding heat, and the minimization of local hot-spots, while still maintaining a very rigid coil bracing, which is amply capable of withstanding all short-circuit stresses.

The heating curve of these armatures, without the blower running, at full load and 50 percent overload, is shown in Fig. 5, which shows reasonably close agreement between the thermometer temperatures of the generator and the temperature indicated by the resistance of the blower operating coil. On full load, the temperatures are so low that no blower is necessary, while at 50 percent overload the temperature indicated by the resistance of the indicating coil is slightly higher than the thermometer temperature of the armature. It is desirable to have incorporated in the indicating device a conservative margin of safety to offset any local hot spots which might exist in the machine. This curve is extremely interesting because of the ready comparison it affords between the short time rating of a high-speed machine and its continuous temperature rating at the same load. High-speed machines necessarily have a relatively small thermal capacity, resulting in a rapid increase in temperature when a heavy overload is applied. It is thus entirely possible seriously to overheat a machine which has exceptionally good commutating characteristics at loads very much below the load where sparking begins to appear on the commutator. The temperature of this machine with the blower in operation, is materially lower than that shown on the curve, the difference representing a virtual increase of machine capacity to handle heavy loads of long duration.

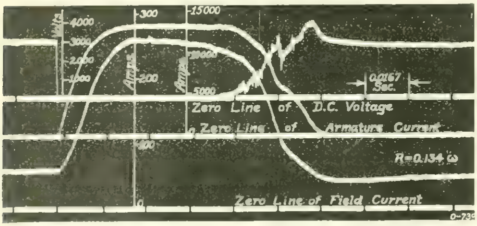

FIG. 9—DIRECT-CURRENT SHORT-CIRCUIT TEST AT 9.25 LOAD

ELECTRICAL CHARACTERISTICS

The generators of this set are of the six-pole, shunt-wound compensated type, and are equipped with a flash suppressor.* The use of shunt-wound machines is rather unusual in low voltage railway work, where non-compensated commutating-pole machines are found satisfactory, because such machines usually have a very decided drooping voltage characteristic. Shunt-wound compensated generators, however, by eliminating all internal electrical distortions have only a very slight droop in voltage under load, and have the decided electrical advantage on a high-voltage outfit of allowing a very clean construction of the stator parts, with ample room for the necessary compensating windings, and allowing a general simplification of the entire stator construction by the omission of the series coil wiring. The slight droop in voltage characteristic insures great stability in parallel operation and is actually no handicap in this class of service, where close voltage regulation is never desired. The operation of shunt-wound generators, when running inverted (regenerative) in parallel with other sets, is inherently superior to that of compound wound generators, which must necessarily run as differential motors. The stator construction of these machines is shown in Fig. 8.

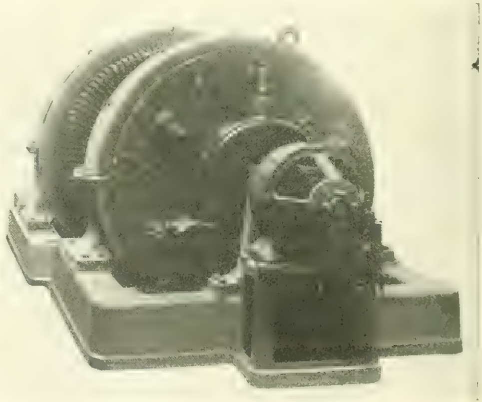

FIG. 10—COMMUTATION AT 9.25 LOAD

The six-pole construction of machines as large as these is rather unusual, when compared with moderate voltage constructions. Flashing at the commutator during overloads, or partial short-circuits, is a severe handicap to a machine's usefulness, and a positive detriment to its reliability, and the use of the six-pole construction is necessary in order to obtain the maximum inherent immunity from flashing, and to allow the requisite freedom in design to meet the unusual commutating performance characteristics which these sets have. The likelihood of flashing in a direct-current machine is fundamentally dependent upon the distance between brush arms, which distance is limited by the mechanical conditions governing commutator peripheral speed. This speed is proportional to the distance be-

*See article on "The Flash Suppressor" by N. W. Storer and F. T. Hague, in the JOURNAL for May, 1918, p. 144.

tween brush arms, and the armature frequency in cycles per second or, in other words, the permissible distance between brush arms for a conservative commutator speed is inversely proportional to the armature frequency, or the number of poles. Thus, for a given machine speed, the high-voltage machine must have fewer poles* than a moderate voltage machine, if it is to have the same margin of safety in operation. In order to provide the maximum inherent immunity from flashing, and to obtain the maximum commutating performance of which the machines are theoretically capable, these machines were built with the minimum number of poles which allowed a balanced mechanical design. This is consistent with experience, which has always proven that low frequency machines have better inherent commutating characteristics than higher frequency ones.

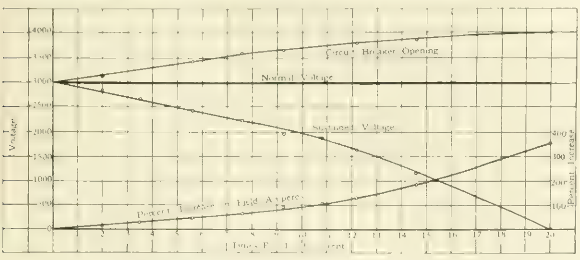

FIG. 11—DIRECT-CURRENT TERMINAL VOLTAGE CHARACTERISTICS
From oscillograph tests. The flash suppressor was not used during these tests.

The commutating pole construction, shown in Fig. 7, is unusual in that the tip of the pole which carries the winding has a large tapered body section insuring an unsaturated magnetic circuit at extreme overloads. The tapered pole body is so proportioned as to utilize to the fullest possible extent all of the space available between the main pole tips for the commutating pole and winding, and allows the rear half of the pole which carries no winding, to be made of very large magnetic section. The momentary overload commutating capacity of a machine is directly dependent upon the maintenance of an unsaturated magnetic circuit as the following considerations will show. Current is dělivered from a direct-current generator to its line through the process of commutation, which in order to be successful, requires that each armature coil must have its current completely reversed each time the bars to which it is connected pass under a brush. The reversal of current in an inductive armature coil necessarily involves a change of magnetic energy in the coil, and unless this change is accomplished while the coil is still short-circuited by the brush, it will be evidenced by an arc, as the coil breaks contact with the brush. It is the theoretical function of commutating poles to accomplish this energy change in the commutating coils, and to the extent to which they fail to reverse the load current in the allotted time, sparking results. For perfect operation, the commutating pole strength must increase directly with the load current, and this requires the poles to be proportioned magnetically so as to use the space available for them to the fullest advantage. Commutating poles of tapered body section represent the maximum which can be done to improve the effectiveness of the commutating poles at very high loads. This construction logically involves making all of the magnetic circuits of very generous proportions in order to avoid the detrimental effects of saturation, even at peak loads, and accomplishes its result of extending the commutating limits, only by a considerable increase in size of the various magnetic circuits.

The commutator neck insulation, and the insulation between the necks and the armature winding coil support have always been the weakest points of direct-current armatures from the insulation stand-point, and it was considered necessary to develop an improved type for 3000 volt service. It consists of a moulded mica ring, extending from the rear of the commutator, up along the back of the commutator necks to the armature winding, and extending over the top of the front coil support. This mica is supported and protected by a casting, bolted to the rear of the commutator V-ring. Further protection against dirt is obtained by packing between the commutator necks with a filling material, as shown in Fig. 5, which, after baking, is turned off flush with the necks. The commutator front V-ring is heavily insulated bv asbestos duck, which is impregnated with varnish and baked in place.

TEST COMMUTATING CHARACTERISTICS

The commutating performance of these machines was tested by tripping a circuit-closing switch, thus establishing a circuit through a bank of non-inductive grid resistances, and interrupting this overload current by means of a slow-speed circuit breaker which opened in about 0.10 second. Thus the loads were applied at a much more rapid rate than in normal railway service, because the trolley line has an appreciable reactance which tends to slow down the rate of current increase on partial short-circuits. The commutation of these machines was practically sparkless at loads up to

TABLE I—SUMMARY OF THE DATA OF THE COMPLETE SERIES OF SHORT-CIRCUIT TESTS, MADE AT 3000 VOLTS NO LOAD

Times Load	Circuit Resistance	Sustained D. C. voltage	Percentage increase field amps.	Initial rate of current increase per sec.
1.0	4.5	2900	10	570 000
2.0	2.16	2800	20	620 000
3.5	1.22	2650	30	710 000
5.5	0.78	2450	45	850 000
7.5	0.56	2200	62	840 000
9.0	0.46	1050	90	940 000
11.0	0.39	1850	105	1 050 000
12.0	0.34	1600	125	1 070 000
15.0	0.26	1150	180	1 110 000
20.0	0.13	0	350	1 150 000

*See article on "Factors that Determine Maximum Rating of a Direct-Current Machine" by F. T. Hague in the JOURNAL for Feb. 1918, p. 42.

ten times normal. At currents between 10 and 15 times normal, sparking began, and the brushes emitted some slight fire, which did no damage to the brushes or to the commutator surface, and the machine showed no tendency whatever to flash over. Between 15 and 20 times normal current, a small flash was generated under the brushes which, however, was prevented from going to ground by asbestos board shields mounted on the outer end of the brush rigging, as shown in Fig. 1.

It is thus possible to short-circuit these machines at 3000 volts without any external resistance, and open this dead short-circuit by a slow-speed circuit breaker, as shown in Fig. 9, after a time interval of 0.1 second without any damage to the machines or brush rigging that will prevent them from continuing on in normal service without a shut-down. A visual idea of the commutating conditions may be obtained from Fig. 10, which shows the sparking at the commutator at 9.25 times normal full-load current. This photograph was taken at a lens opening of F-11, which shows more fire on the photograph than is evident to the eye. Photographs of commutating conditions are not capable of correct interpretation, unless the lens opening and the circuit breaker speed are stated, because the film is a light value integrating device, and the slower the circuit breaker speed, the greater the impression on the film.

It has been possible to obtain a complete oscillographic record of the machine's terminal voltage, armature current and field current on various loads, up to the dead short-circuit value. This data shows that the machines have an unusual power of maintaining voltage under very heavy overloads, the voltage regulation being an absolutely straight line on loads up to ten times normal, with only a slight droop at much higher loads. This is the direct result of thorough electrical compensation and the absence of excessive arcing under the brushes, even at the highest currents. This data is plotted in convenient form in Fig. 11, which shows the terminal voltage under sustained load, the voltage rise on the armatures, due to the sudden interruption of current by the circuit breaker, and the percentage increase in field current which takes place on suddenly applied loads up to the dead short-circuit value. The slight departure of the voltage regulation curve from a straight line at currents beyond ten times normal marks the current at which sparking begins to appear on the commutator and the point at which the field current begins to increase in a faster proportion than the load, and in a general way confirms the data shown in the photograph.

As shown in Table I, the rate of current increase on overload is very rapid on compensated generators, because they have a minimum of reactance. The current increases at an initial rate of 570 000 amperes per second, when full load is thrown on the machine, and the rate gradually increases with increasing magnitude of current until, at dead short-circuit, the current increases at the initial rate of 1 150 000 amperes per second. The circuit resistance given in Table I includes the machine's resistance and the brush contact resistance, which amounts to 0.13 ohms total.

Impulse-Gap Lightning Arresters

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Lightning Arrester Engineer,
Westinghouse Electric & Mfg. Company

The purpose of a lightning arrester is to protect. To do this, it must act with minimum delay, discharge with maximum freedom and restore normal conditions following a discharge with greatest reliability and minimum disturbance. Lightning arrester development began with the last of these requirements and, during early years, most attention was devoted to methods of stoping the arc following a discharge. Many types of arresters were brought forth, of which nearly all used a simple spark gap and had limited freedom of discharge, due to the use of resistances in one form or another. As power systems grew large, attention was directed more to the development of types having greater discharge rates, culminating in the aluminum electrolytic arrester which, when properly maintained, still remains the most efficient of all arresters, once it has started to discharge.

Here and there, however, cases were noticed where even the best electrolytic arresters failed to give protection and sometimes failed to discharge. This made it clear that in commercial arresters some vital and essential element was lacking. Finally it was realized that this was the quality mentioned first above, namely, speed of action or, technically speaking, low time constant of discharge.

This was made worse by the growing tendency to assume that, because an electrolytic arrester was much more expensive than any other type, it could be made to do all the work itself. Therefore, choke coils have grown smaller and smaller until many commercial forms are of negligible value, and sometimes none are used at all. An adequate choke coil can delay a surge so as to give the standard electrolytic arrester time to discharge, and thus protect the apparatus behind the choke coil. However, by piling up the voltage outside the coil, it would make the danger of breaking down the insulation of the line still greater.

It became evident, therefore, that the vital line of improvement lay in reducing the "time constant" or "dielectric spark lag" of the gaps used with the arresters. A good deal could be accomplished along this line by applying to arrester gaps the principles already learned in connection with measuring gaps for high voltages. In that field, the sphere gap had long dis-

placed the needle gap, and it was only a small step, therefore, from the plain horn to the sphere gap on arresters.

The adoption of the sphere gap brought into more current use the term "impulse ratio". As applied to arrester gaps, "impulse ratio" means the ratio of discharge voltage on high lightning frequencies to the discharge voltage of the same gap on low commercial frequencies. A high impulse ratio obviously means poor lightning protection and, in general, the ratio will be greater than unity whenever the gap length is much greater than the diameter of the spark gap electrodes. This is because the formation of a brush discharge must precede actual breakdown of the gap and, as this requires energy, it necessarily requires a finite time. During this time interval, while the brush is being formed, the voltage of the surge can keep on rising to a greater and greater percentage above the real breakdown value

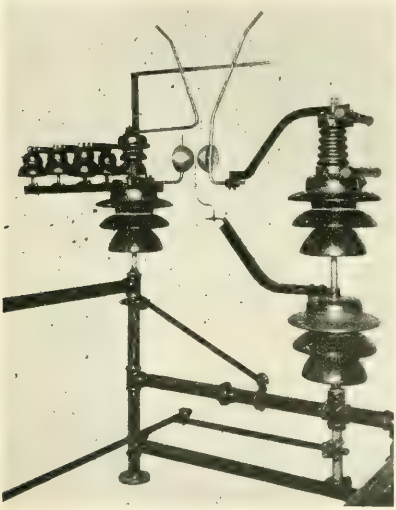

FIG. 1 IMPULSE SPARK GAP

depending on the frequency of the surge. This is illustrated in Fig. 2 in which V_2T_2 represents the point and time of breakdown of a properly designed sphere gap which has no time lag. V_1T_1 shows the point to which the voltage can rise, due to the time lag where an ordinary horn gap is used. V_3T_3 on the other hand, shows the earlier discharge and quicker and better protection resulting from the lower voltage breakdown of the impulse gap described below, due to its selective property. It follows, therefore, that a needle gap is the worst of all, and tests show that it can have an impulse ratio of greater than *2* to *1*, while a properly proportioned sphere gap will have practically a unity ratio.

This change to sphere gaps, however, had suggested a new line of development that was not destined to stop there. The improvement gained by adding spheres was not great enough to be considered final. Below 11 000 volts, there was no improvement at all, while up to, say, 66 000 volts the improvement was only a comparatively small percentage, since the gap settings used were not wide enough to accentuate the difference in speed between a sphere and the comparatively large diameter horns used, for the plain horn gap becomes inferior only when the gap setting is much greater than the diameter of the horn.

At first it was thought that unity impulse ratio represented perfection and that nothing more could be expected of a gap than that it should discharge lightning frequencies at least as well as commercial frequencies. This, however, is the age of specialization and it was only natural that it should occur to engineers that if an arrester existed primarily to discharge high frequencies, it ought to be possible to breed into it an especial keenness of scent along that line, so that it would select out high frequency surges and give them special attention, letting harmless low frequency surges, due to switching, load changing, etc. pass on undisturbed.

The problem presented itself, therefore, of providing a gap that would be automatically more sensitive to high frequencies than to low. Obviously some combination of inductance or capacity must be used when dealing with matters of frequency. For simplicity's sake, capacity was chosen, since it was already available in the arrester, namely, the capacity of the gap insulators as condensers, and this improved device has been given the name of the "impulse gap" since it is especially sensitive to sudden impulses.

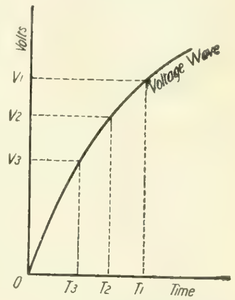

FIG. 2—TYPICAL CURVE OF HIGH-VOLTAGE WAVE

The scheme adopted is essentially a Wheatstone bridge that is balanced at low frequency and unbalanced at high frequency. Fig. 3 shows the fundamental circuit in which $C_1 = C_2$ and $C_3 = C_4$, all being capacities. A and B therefore, are both neutral points and can be connected together without disturbing the equilibrium of the system. Likewise, if AB is a small diameter conductor, it can pass through the center of spark gap SG without materially affecting the breakdown voltage of the gap. R is an inductive impedance, or in the commercial design, a high resistance that is low enough, however, in comparison with the impedances C_3 and C_4 to be negligible at commercial frequencies, and thus not disturb the balance of the bridge.

At normal frequencies, therefore, the arrangement shown in Fig. 3 constitutes a balanced bridge, since the resistance of R is negligible in comparison with the impedances of C_3 and C_4. At high frequencies, however, such as lightning surges, the latter impedances become very small compared to R and almost all of voltage E

is piled up across the one arm of the bridge including C_4 and R. The tendency of the gap between AB and G to break down is thus greatly increased. As soon as it breaks down, the gap between AB and S naturally follows.

In the commercial construction, the capacities C_1 and C_2 are provided by the gap itself, while C_3 and C_4 are formed by the insulator column supporting the line side of the gap. AB takes the form of an auxiliary electrode extending from the middle of the insulator column, consisting of C_3 and C_4, to the center of the gap. In Fig. 4 is shown approximately the standard 66 000 volt construction. The two insulators under the line side of the gap form condensers C_3 and C_4, and the capacities between the intermediate electrode of the gap and the two spheres or horns respectively form C_1 and C_2.

A very valuable feature of the impulse gap is that it is not necessary to sacrifice any good feature of previous practice. The sphere gaps can be retained and the same settings used as experience has shown best. If the auxiliary electrode AB is removed, there remains an arrester identical in characteristics, but with somewhat better insulation than the best designs previously available. If, at any time, it is desired to eliminate the impulse gap feature AB can be removed in a few moments without disturbing any other part and no change of adjustment or gap setting need be made.

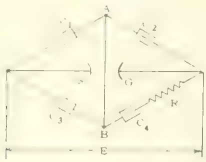

FIG. 3—SCHEMATIC DIAGRAM OF IMPULSE GAP

One feature remains to be noted which might otherwise be overlooked, namely that for best results the electrode AB, should be not a sphere, but a small diameter point. The smaller the better so long as it does not burn away too rapidly. This is because the use of a point electrode makes the breakdown voltage of half the gap equal to only about one-fourth that of the whole sphere gap, whereas with a sphere it would be approximately one-half.

Inch for inch of separation, the needle gap gives better protection than the sphere gap, but ordinarily, a needle gap has to be set so much wider for a given voltage breakdown that it is much inferior, from a protective standpoint. In the impulse gap, however, the arrester discharge is determined by a needle gap on high frequencies and by a sphere gap on low frequencies. Due to the use of the balanced bridge, the needle gap is prevented from discharging on normal frequency, so that it can be made only one-half as long as the sphere gap instead of say twice as long. When the sphere gap for arresters was first brought out, it was claimed, and claimed correctly, that it was as good as a needle gap of half the low frequency discharge voltage, but it could not be, and was not claimed that it could anywhere near equal a needle gap of one-fourth the low frequency discharge voltage, such as determines the protection given by the impulse gap. The possibility of getting the benefit of such a low gap setting is the new contribution of the impulse gap. It makes possible the obtaining of an impulse ratio of almost any desired value. As low as 0.3 is possible, but such a value is lower than is ever likely to be desired. A reasonable and feasible arrangement in commercial service would be a gap set for 50 percent above normal voltage at normal frequency and which, due to the impulse feature, would discharge at line voltage on a 500 000 cycle surge.

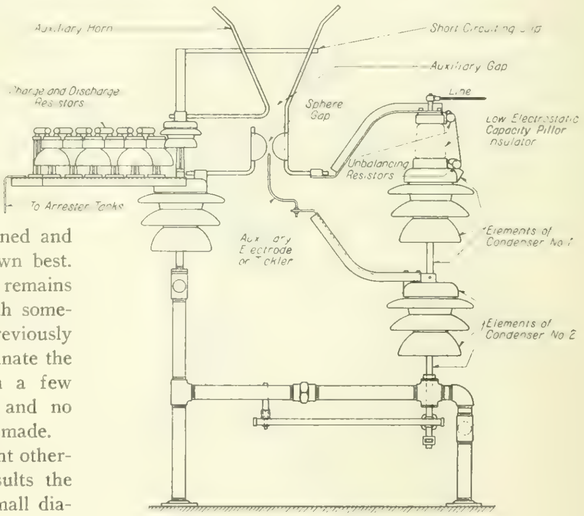

FIG. 4—TYPICAL CONSTRUCTION OF IMPULSE GAP

Heretofore, no such protection was obtainable from a spark-gap arrester, but it is now easily accomplished with the impulse gap. It is obvious too that the impulse gap feature is not limited to the electrolytic arrester alone, but may be used with any other type. It has been said that the impulse gap is not faster than the sphere gap, but that the reason it works better is that it starts sooner. Of two equal gaps, the one that starts first will surely give the better protection. The impulse gap is a big step forward in protection, but its possibilities are not yet exhausted and development is not yet at an end along this line.

Fuel Burning Equipment of Modern Power Stations

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War necessities brought about, to a certain degree, "conventional" steam power plants. The activities of the different Government administrations, however, have exacted requirements, in detail, conducive to the highest economic operating results. Production, on the one hand, has made the different public service corporations face the necessity of increased power facilities, and the requirements of fuel conservation, on the other, have demanded a careful study of detail problems, not only in the selection of equipment, but in providing means for its economical operation. The co-operative activity of the power plant management, with all these problems, cannot be better exemplified than in the character of the equipment designed for recent installations of new steam plants.

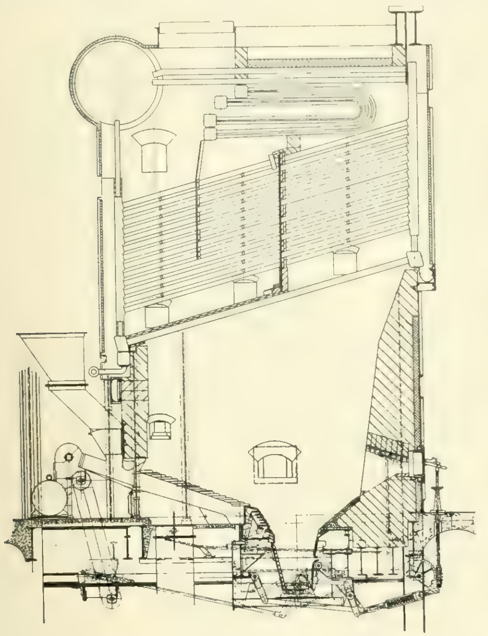


FIG. 1—BOSTON EDISON STOKER SETTING
Showing clinker grinder and furnace control mechanism located at the front of the boiler.

A study of the fuel burning equipment of the most modern plants will show that every consideration is being given to those details which provide for a balancing of the economic results that come from a careful selection of equipment, good supervision and correct operation. It will be found that elaborate means are being provided so that the boiler room organization can do things easily. It is no longer necessary for firemen to climb ladders and crawl over the boiler tops to change the position of dampers, although such methods are still common in many old plants. Mechanisms are being placed at the hands of the operators so that it is not necessary for them to go to inconvenient places in order to control operating conditions.

The most generally used fuel burning equipment in the modern stations is the "inclined multiple retort" underfeed stoker, designed for large boiler units, ranging from 1200 to 1500 hp. A number of boilers containing 12 600 sq. ft. of heating surface have been used and are furnishing steam for 7000 to 8000 kw in the prime mover. It is not at all improbable that this unit will be further developed to furnish steam for at least 10 000 kw., in the prime mover for continuous operation. These units are set singly with large alley ways between each setting, so that the boiler and fuel-burning equipment are accessible on all sides. The stokers are designed for a flexible operation of 50 to 300 percent rating. Clinker grinders are used in a number of cases for discharging the ash and refuse automatically.

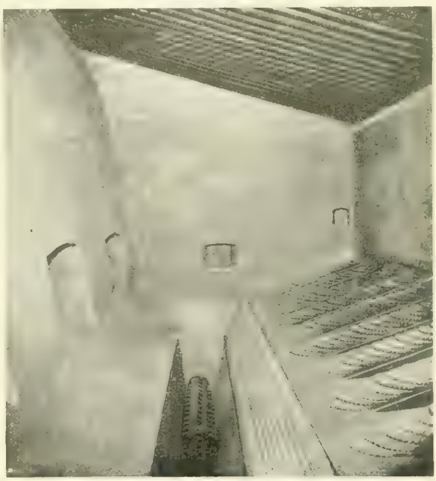


FIG. 2 INTERIOR VIEW OF BOSTON EDISON FURNACE
Showing clinker grinder and front wall of construction.

The following brief description of the fuel-burning equipment recently installed in a number of modern power stations covers a wide range in the character of load and fuel used. Some of these plants are completely new stations, while others are extensions to old stations, and still others are old stations in which inade-

quate fuel-burning equipment has been replaced by more modern equipment.

EDISON ELECTRIC ILLUMINATING COMPANY OF BOSTON

This Company has replaced old fuel-burning equipment under eight 512 horsepower boilers with inclined

FIG. 3—FRONT VIEW OF BOSTON EDISON STOKERS
Showing motor driving equipment.

underfeed stokers. One of these stokers was equipped with a clinker grinder, the idea being to try this out under regular operating conditions and with the fuel available, this being a part of a study for the new ex-

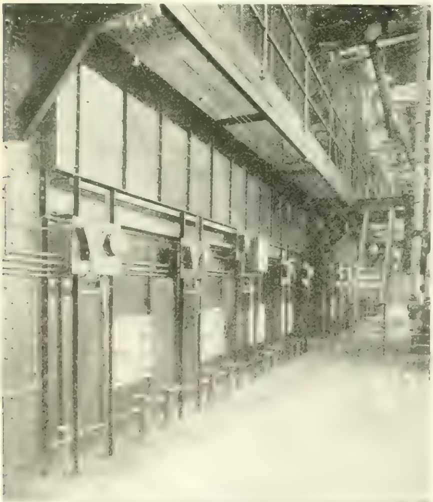


FIG. 4—REAR VIEW OF BOSTON EDISON BOILERS
Showing instrument boards and location of furnace control mechanism; also the location of the doors in the bridge wall.

tension to the station. Although the stoker was of small size (five retorts), the clinker grinder operated satisfactorily and it was decided to use this design in connection with the equipment for the new extension consisting of four cross-drum boilers, 42 sections wide,

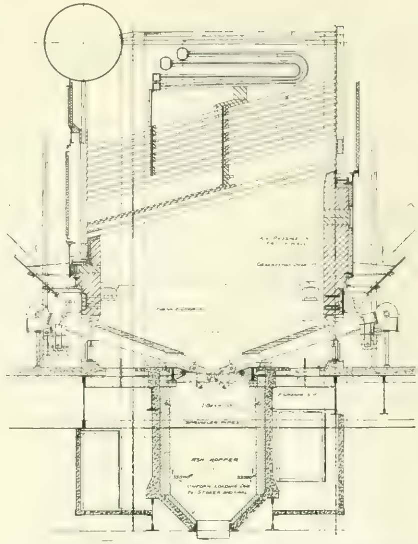


FIG. 5—SETTING OF BUFFALO GENERAL ELECTRIC STOKERS
Showing the method of admitting air over the fire through the front and rear walls.

14 tubes high and 18 ft. long, rated at 1232 hp., at 300 lb. gage pressure equipped with a superheater designed to give 150 degrees superheat.

These stokers, as shown in Fig. 1, are of the un-

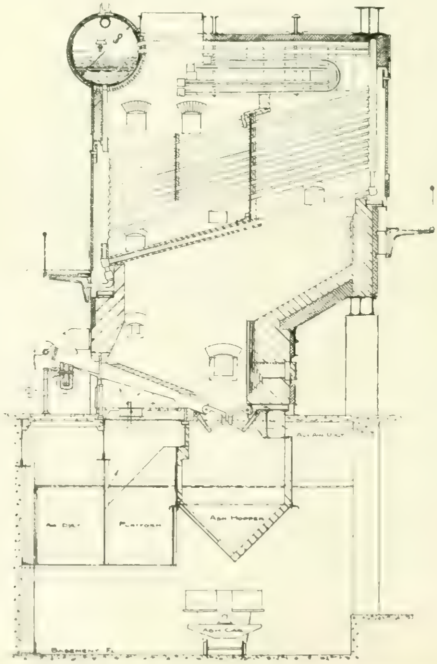


FIG. 6—STOKER AND BOILER APPLICATION OF THE UNION GAS & ELECTRIC COMPANY, CINCINNATI

derfeed type, having 13 retorts installed under the back end of the boiler, under the mud drums, and equipped with rotary clinker grinders, Fig. 2, for removing the ash and clinker continuously. The stoker drives Fig. 3,

FIG. 7—MOTOR AND CONTROL MECHANISM OF THE STOKER EQUIPMENT
At the American Gas & Electric Company plant at Windsor, W. Va.

are divided with not over four retorts to a motor; also, the wind boxes and dampers are so arranged that they can be controlled on the same basis, this provision being made so as to give a complete control of coal and air across the entire furnace width.

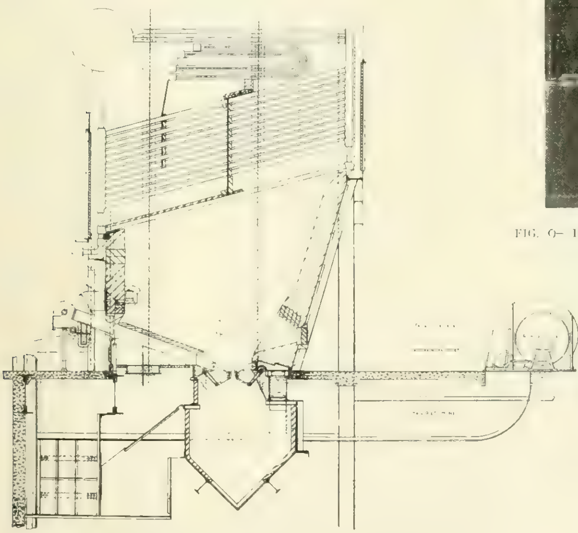


FIG. 8—STOKER AND BOILER EQUIPMENT AT THE AMERICAN GAS & ELECTRIC COMPANY PLANT

The coal usually used is New River of approximately the following analysis:—

Fixed carbon	73.50
Volatile	20.75
Ash	5.75
Moisture	3.25
Sulphur	1.05
B. t. u.	14700

The average percent of combustible in the ash and refuse is not to exceed 15 percent. The stoker equipment, when supplied with the above fuel, is designed to develop 300 percent of normal rating of the boilers for periods of short duration.

The Boston Edison engineers worked out a design in which doors are placed in the bridge wall and all controlling mechanism placed at the end opposite the stokers, Fig. 4, so that when the operator views the furnace fires through the bridge wall doors, he will have at hand the controlling mechanism.

BUFFALO GENERAL ELECTRIC CO.

The fuel-burning equipment for a recent extension of this Company's boiler plant consists of 24-retort un-

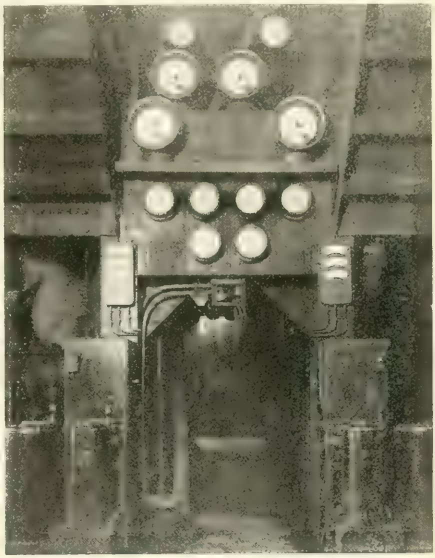


FIG. 9—INSTRUMENT BOARD USED IN CONNECTION WITH THE STOKERS AND BOILERS SHOWN IN FIGS. 7 AND 8

derfeed stokers applied to 1140 hp cross-drum boilers, Fig. 3. The stoker equipment is designed for burning high volatile Pittsburgh coal of about 13 500 B.t.u. as fired, 10 percent ash, 3 percent moisture and two percent sulphur. Air admitting dump grates are furnished with the stoker equipment, these being power-operated. To eliminate, as much as possible, the formation of clinker, air boxes were designed for installation in the side wall.

The combined efficiency for the plant's operating conditions will range from 75 percent at 200 percent of boiler rating, to 65 percent at 500 percent of boiler rating. The coal burning equipment is designed for continuous capacity of 480 percent of boiler rating and 600 percent for short durations. In comparison, this boiler has 24 retorts installed under an 1140 hp boiler, while at the Delray Station of the Detroit Edison Company, there are 26 retorts installed under a 2365 hp boiler.

UNION GAS & ELECTRIC CO., CINCINNATI

The new \$8 000 000 plant of this Company contemplated the installation of eight cross-drum type boilers containing approximately 12 625 sq. ft. of water heating surface, with superheaters to produce 250 degrees superheat. Each boiler was made up of 42 sections each, 13 tubes high and 20 ft. long, the furnace width being

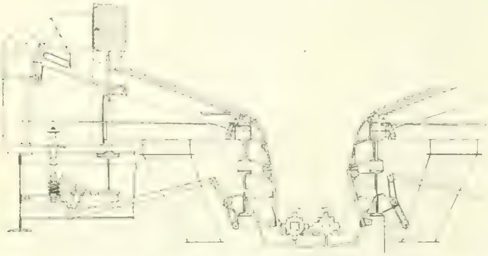
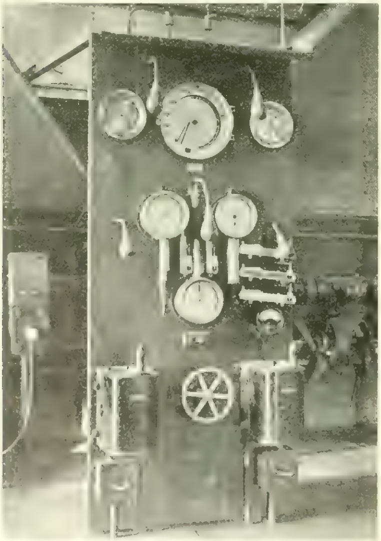


FIG. 10—SECTIONAL VIEW OF STOKERS AT THE DELRAY STATION OF THE DETROIT EDISON COMPANY

Showing clinker grinder and the curved grate surface.

24 feet inside the setting walls. Each boiler is equipped with economizers over the boiler and each boiler, with its economizer, is designed for evaporating 100 000 pounds of water per hour continuously from 100 degrees to steam at 250 pounds pressure, and superheated 250



[illegible] DELRAY STATION

[illegible] steam gauges, CO_2 recorders, draft gages, motor controls and forced draft controls mounted on a single panel.

degrees, Fig. 6. The entire equipment is capable of evaporating 120 000 of water under the same conditions for short periods. The fuel-burning equipment is designed for burning West Virginia coal from the Kanawa District, containing approximately 12 500 B.t.u. per pound as fired.

The stoker equipment is of the underfeed type, each stoker containing 14 retorts placed under the rear of the boiler under the mud drum. The stokers consist of double dumping grates with arrangements for admitting air to them. The fuel-burning equipment is designed for combined efficiency ranging from 75 percent, with a boiler capacity of 35 000 pounds of water, to 65 percent with a capacity of 100 000 pounds of water. Each stoker is driven independently by direct-current motors connected by Morse silent chain drives to the line shaft of

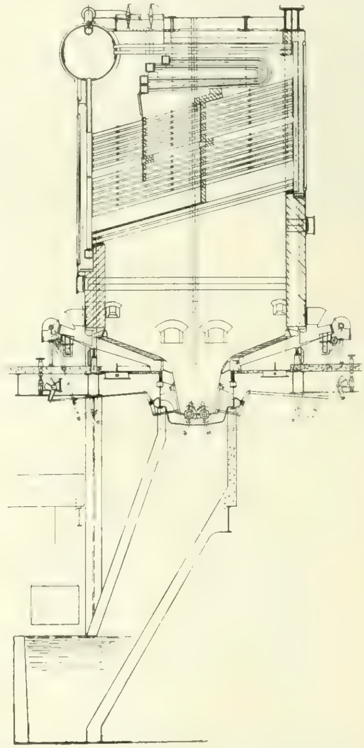


FIG. 12—SECTIONAL VIEW OF STOKER AND BOILER APPLICATION FOR THE WEST PENN POWER COMPANY'S NEW STATION, PITTSBURGH, PA.

the stokers. Instrument boards are installed to indicate to the operators the exact furnace conditions.

AMERICAN GAS & ELECTRIC CO., WINDSOR, W. VA.

The \$10 000 000 plant of this Company, located in the coal fields of Pittsburgh, is one of our largest power plant developments of recent years. The present boiler-room equipment, Fig. 7, either installed or provided for, consists of 14 boilers with underfeed stokers similar to the equipment mentioned for the Union Gas & Electric Company. The setting of the stokers is shown in Fig. 8, and the instrument boards, as shown in Fig. 9, are placed between each boiler in the aisles.

DETROIT EDISON COMPANY

The front view of the boiler and stoker equipment installed at the Delray plant of the Detroit Edison Company is shown in Fig. 10. This consists of 2365 hp

boilers equipped with 26-retort underfeed stokers, with clinker grinders. The Detroit Edison Company engineers have done considerable work in the development of these clinker grinders. Difficulty was at first experienced on account of the fuel bed breaking, where the fuel left the underfeed part of the stoker, and going into the ash well. It will be noted from Fig. 10 that the grate surface has been curved, this being done in order to eliminate the breaks in the fire. This equipment is run ordinarily at about 150 percent of boiler rating, but higher capacities can be obtained when necessary. The coal used contains about 13 200 B.t.u. as fired, and 10 percent ash. Under the above operating conditions, the combustible in the ash runs from 14 to 18 percent.

FIG. 13—UNDERFEED STOKER EQUIPMENT OF THE MINNEAPOLIS GENERAL ELECTRIC COMPANY AT MINNEAPOLIS, MINN.

The instrument board used for indicating to the operators the condition of the furnace is shown in Fig. 11. It will be noted that everything possible is provided to facilitate ease in handling the controlling equipment.

WEST PENN POWER COMPANY, PITTSBURGH, PA.

The new plant of the West Power Company, on the Allegheny River above Pittsburgh, contemplates some decidedly novel features in the boiler and stoker equipment. The initial installation is designed for six boilers of the cross-drum vertical-header type, 42 sections wide, 16 tubes high, 20 ft. long, set with the front header 16 ft. above the floor, each boiler being rated at 1529 hp and equipped with superheaters designed to give 200 degrees superheat. Underfeed stokers are to be installed at the front and rear ends of the boilers, Fig. 12, 14 retorts under the mud drum, and 14 retorts under the front of the boiler. The operating conditions are to be a maximum of 300 pounds gage pressure, 200 degrees superheat.

The boilers will be set in two rows with aisles about 15 ft. between, thus giving plenty of room around each boiler for proper operating facilities. The stoker drives are so divided that there will be 7 or 14 retorts driven by one prime mover, and the wind box dampers are arranged to control separately the air for units of 3 or 4 retorts. The stokers are to be equipped with clinker grinders for continuously removing the ash and clinker. Pittsburgh coals will be used with approximately the following analyses:—

Analysis:—	Coal "A"	Coal "B"	Coal "C"
Fixed carbon	57.38	49.96	56.55
Volatile	34.81	32.84	32.80
Ash	7.81	13.26	10.10
Moisture	5.52	0.94	0.55
Sulphur	1.50	1.20	0.79
B. t. u. (as fired)	13 500	11 748	12 713

The boiler equipment is designed so that the flue gas temperatures will range from 500 degrees at 150 percent rating, to 700 degrees at 300 percent rating, the combined efficiency ranging from 75 percent at 150 percent rating, to 65 percent at 350 percent rating. Each stoker, when burning fuel as mentioned above, is designed to develop 350 percent of boiler rating continuous with the clinker grinder in operation, and 400 percent of boiler rating for peaks of short duration. Under these operating conditions, the combustible in ash is not to exceed 14 percent, and the ash is to be discharged into water-sealed ash pits.

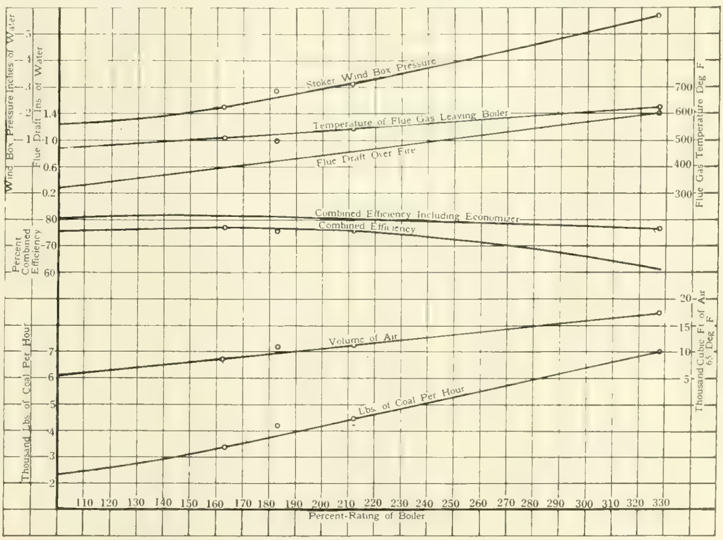


FIG. 14—PERFORMANCE CURVES OF A SIX-RETORT UNDERFEED STOKER AND A 558 HP BOILER
At the Union Electric Light & Power Co. plant, St. Louis, Mo., using southern Illinois coal.

MINNEAPOLIS GENERAL ELECTRIC CO.

The engineers for H. M. Byllesby Company have been very active in redesigning the fuel-burning equipment of plants under their management. For example, at the Minneapolis General Electric Company's plant, Fig. 13, there were installed 12 underfeed stokers under twelve-600 horse-power boilers. A recent extension to this plant contemplates the installation of five-14 retort underfeed stokers under five-1300 horse-power boilers. On account of the coal conditions prevailing

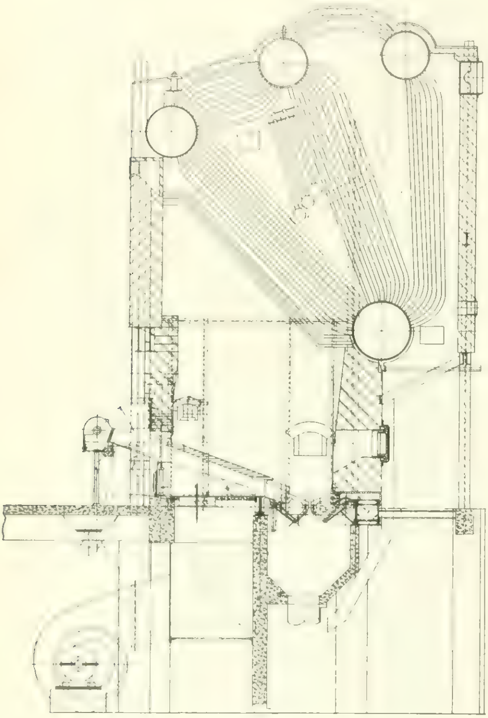


FIG. 15—SIDE ELEVATION OF BOILER AND STOKER APPLICATION IN THE DENVER GAS & ELECTRIC COMPANY PLANT, DENVER, COL.

The lower drum of the boiler is 11 ft., 2 in. above the floor line.

at this plant, it was necessary to design equipment for two grades of coal of the following proximate analyses:

	Coal "A"	Coal "B"
Fixed carbon	50.48	43.49
Volatile	30.81	32.59
Ash	11.03	20.44
Moisture	7.00	10.00
Sulphur	1.70	3.48
B. t. u.	13 400 Dry	11 200 Dry

Under the above conditions, the operating performance of fuel "A" ranged from 1800 to 3000 hp continuous and 4500 hp for short durations. With the poorer grade of coal, the maximum capacity was reduced to 3000 hp for short durations.

UNION ELECTRIC LIGHT & POWER CO., ST. LOUIS

In the past year or so, the boiler plant of the above Company, has been entirely revamped and a change made in the type of fuel-burning equipment formerly used. Careful study was made in regard to the installation of stokers, and it was finally decided to install underfeed stokers for use with good Illinois coal of the folowing analysis:—

Fixed carbon	48.9
Volatile	27.3
Ash	14.9
Moisture	8.9
B. t. u. (as fired)	11 112

The main problem at the start was that of designing the equipment to eliminate, as much as possible, trouble due to clinker formation on the side walls. After the equipment was in operation, and when using the coal that was originally contemplated, very little difficulty was encountered with clinkers. Performance results are shown in Fig. 14. When a grade of coal with the following analysis was used,

Fixed carbon	41.0
Volatile	29.0
Moisture	9.0
Ash	21.7
B. t. u. (dry)	12 000

considerable more attention was required to keep the fires uniform and cleaned properly in order to decrease clinker trouble to a minimum.

DENVER GAS & ELECTRIC CO.

Recent developments in the West have brought about the installation of underfeed stokers for burning coals found in the Denver markets. The above Company's new extension contemplates the installation of four 750 hp boilers and four-9 retort underfeed stokers. The application setting worked out as shown in Fig. 15 was made to give sufficient combustion space for any high volatile coals that were liable to be used at this plant, including lignite. The fuel-burning equipment has been designed for the following coals:—

Fixed carbon	30.00
Volatile	35.85
Moisture	19.70
Ash	5.37
Sulphur	0.42
B. t. u. (dry)	12 000

When using the above fuel, the operating performance ranges from 140 percent boiler rating to 200 percent boiler rating for short duration, with approximately 70 percent combined boiler and furnace efficiency.

Substation Short-Circuits

R. F. Gooding
Commercial Engineer, Westinghouse Electric & Mfg. Co.,
Buffalo, N. Y.

When a substation derives its power from several parallel feeders it may, at a time of short-circuit, develop considerable power. This is true even when these parallel feeders come from one generating station, but when they are in reality tie lines between two generating stations, the power developed at short-circuit is increased considerably. Calculations must be made to determine the stresses to which the apparatus, such as oil circuit breakers, disconnecting switches, bus supports, etc., will be subjected, and if these stresses are found to be excessive, steps must be taken to keep them within safe limits.

If short-circuit conditions were the only factor to be considered, the advisability of supplying substations from tie lines might be questioned, but there are times when this is highly desirable in order to get the proper amount of flexibility in operating and switching conditions. Then again, the geographical layout may be such as to render this the only feasible scheme, as for example in a city located at the juction of two rivers, with a power station on each river, and tie lines between the two stations. These cables may run through the city, and a great amount of local distribution may be necessary, say, at the center of the city. Obviously, then, supplying this central substation from these tie lines is highly desirable, so far as flexibility of switching and continuity of service are concerned.

In the following discussion all current values are root mean square values. An oil circuit breaker will hardly open in less than 0.3 of a second, and it is assumed that, by that time, all dissymmetry in the short-circuit will have disappeared. The values given are therefore on the basis of symmetrical short-circuits. Further, on account of the great amount of reactance present in the generators, cables etc., the generators will be considered capable of maintaining full bus voltage at the substation, even in case of a bus short-circuit. This means that there will be practically no diminution of current by the time a circuit breaker opens. It will therefore have to rupture maximum instantaneous current for symmetrical short-circuits. In these calculations only the reactance of the generators, cables, etc. will be considered, no attention being paid to resistance or capacitance. The results are given to the nearest thousand k.v.a. as, in the values of the size obtained here, a difference of a few hundred k.v.a. more or less would not be noticed.

For a typical example of such an installation, assume a system as shown in Fig. 1. Station A has six 25 000 k.v.a., 13 200 volt generators, each having an inherent reactance of eight percent. The bus is divided into three sections, with a bus sectionalizing reactance of eight percent at 50 000 k.v.a. between sections. Station B has one 35 000 k.v.a. generator of 10.5 percent reactance, four 30 000 k.v.a. generators of 12 percent reactance and one 25 000 k.v.a. generator of 15 percent reactance, all at 13 200 volts. A reactance (nine percent at 50 000 k.v.a.) sectionalizes the bus, as shown.

Between stations A and B (50 000 ft.) consider six tie lines, each consisting of a 500 000 circ. mil, three conductor, lead-covered cable, having a reactance of 0.15 percent per 1000 ft. at 8000 k.v.a. (approximately 350 amperes at 13 200 volts). The distance from station A to substation X is taken as 30 000 feet and this gives a cable reactance of 4.5 percent. Station B is 20 000 feet from substation X giving a cable reactance of three percent. At each station there will be in each feeder a reactance of 2.5 percent at 8000 k.v.a. The

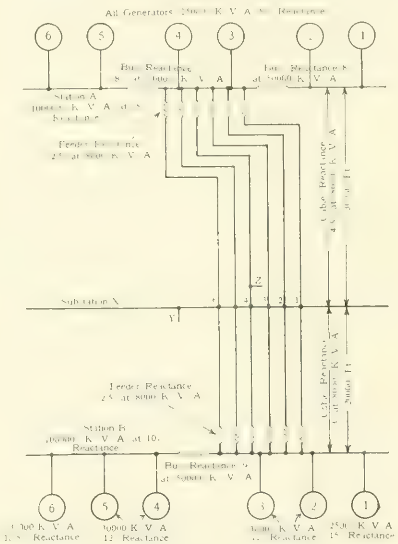


FIG. 1—(SCHEME I) SINGLE LINE DIAGRAM OF 13 200 VOLT SYSTEM

total reactance then, of each circuit from station A to substation X will be seven percent at 8000 k.v.a.; while that from station B to substation X will be 5.5 percent at 8000 k.v.a.

For facility of comparison, each station is brought to the basis of 100 000 k.v.a. with its equivalent reactance. For instance, a 25 000 k.v.a. machine with ten percent reactance will, at time of short-circuit, develop 250 000 k.v.a.; a 50 000 k.v.a. generator with 20 percent reactance would develop the same amount; and a 100 000 k.v.a. machine (if such a machine were possible) with 40 percent reactance, would give the same results. Therefore, a 25 000 k.v.a. generator with ten percent reactance, so far as short-circuits are concerned, is the equivalent of 100 000 k.v.a. at 40 percent

reactance. Now, if all machines are brought to the same basis they can be compared much more rapidly. However, instead of treating the machines as separate units, it is desirable to get the equivalent reactance of each station in terms of 100 000 k.v.a.

At station *A*, generators *1* and *2* would give 50 000 k.v.a. at eight percent reactance on short-circuit. Any power going from the right hand section to the middle section must necessarily pass through the bus sectionalizing reactance (eight percent at 50 000 k.v.a.) so this reactance must be added to that of the generators. The power that generators *1* and *2* will supply to the middle section through the bus reactance will therefore be 50 000 k.v.a. at 16 percent reactance. Machines *3* and *4* will contribute 50 000 k.v.a. at eight percent react-

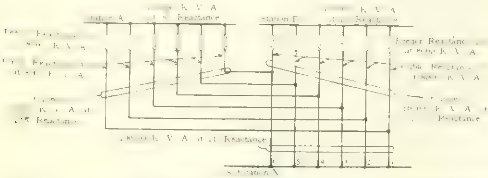


FIG. 2—(SCHEME I) WITH NO REACTANCE AT THE SUB-STATION THE SHORT-CIRCUIT CAPACITY EQUALS THE SUM OF THE CAPACITIES OF THE TWO STATIONS

ance, and generators *5* and *6* on the left hand section will give the same amount over the bus reactance as *1* and *2*. The total power on the middle section will be that from generators *1* and *2* through the bus reactance or 50 000 k.v.a. at 16 percent reactance (which equals 25 000 k.v.a. at 8 percent) plus that from generators *3* and *4* direct, which equals 50 000 k.v.a. at 8 percent reactance, plus that from generators *5* and *6* through the bus reactance (50 000 k.v.a. at 16 percent reactance or 25 000 k.v.a. at 8 percent). The total equals 100 000 k.v.a. at 8 percent reactance. Therefore the equivalent power on the middle section of station *A* bus is 100 000 k.v.a. at eight percent reactance.

At station *B* the machines must be put on a common basis, so far as reactance is concerned, before their capacities can be added. The figures may be taken as 12 percent for the left section and 15 percent for the

TABLE I—CURRENT VALUES OF A SHORT-CIRCUIT ON 13 200 VOLT BUS AT Y

[illegible]	Total K.V.A.	Total Amperes	Amperes from Station A	Amperes from Station B
1	[illegible]	10 200	4 630	5 570
[illegible]	418 000	18 400	8 500	9 900
[illegible]	[illegible]	25 000	11 700	13 300
[illegible]	[illegible]	30 700	14 600	16 100
[illegible]	815 000	[illegible]	17 200	18 500
[illegible]	910 000	40 000	19 500	20 500

right. Any value could be used, just so all machines are brought to the same basis. The power on the left section will be that from one 35 000 k.v.a. generator at 10.5 percent reactance (which equals 40 000 k.v.a. at 12 percent) plus that from two 30 000 k.v.a. generators at 12 percent reactance, giving a total of 100 000 k.v.a. at 12 percent reactance. The power from the left section would have to go through the bus reactance (nine percent at 50 000 k.v.a. or 18 percent at 100 000 k.v.a.). Then the total power from the left hand section through the reactance equals 100 000 k.v.a. at 30 percent reactance (which equals 50 000 k.v.a. at 15 percent). The power on the right hand section will be that from one 25 000 k.v.a. generator at 15 percent reactance, plus two 30 000 k.v.a. generators at 12 percent reactance (which equals 75 000 k.v.a. at 15 percent) giving a

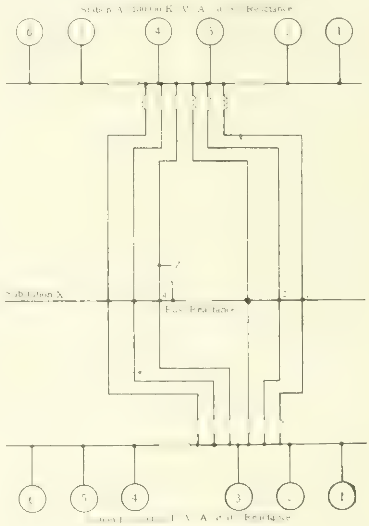


FIG. 3—(SCHEME II) SINGLE LINE DIAGRAM OF SYSTEM WITH BUS REACTANCE

total of 100 000 k.v.a. at 15 percent. Then the total power on the right section will be that from generators *4*, *5* and *6* through the reactance (50 000 k.v.a. at 15 percent) plus that from generators *1*, *2* and *3* direct (100 000 k.v.a. at 15 percent reactance) giving a total of 150 000 k.v.a. at 15 percent reactance, equivalent to 100 000 k.v.a. at 10 percent reactance. Therefore the equivalent power on the right section of station *B* bus equals 100 000 k.v.a. at ten percent reactance.

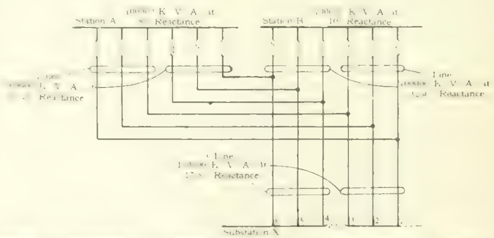


FIG. 4—(SCHEME II) SHORT-CIRCUIT CAPACITIES WITH A REACTANCE IN THE SUBSTATION BUS

It is at once evident that the bus reactances have been assumed of such value as to make the equivalent power of each station come out in even figures (eight percent reactance for station *A* and ten percent for *B*).

SHORT-CIRCUIT AT SUBSTATION X WITH NO REACTANCE AT SUBSTATION

Consider first the conditions existing at substation *X* with connections as indicated on Fig. 1, with no reactance at the substation. With only one tie line (say No. *1*) on the bus, the power concentrated on the bus in case of a short-circuit would be 232 000 k.v.a., or 10 200 amperes at 13 200 volts. Of this amount station *A* contributes 105 000 k.v.a. (4630 amperes) and station B, 127 000 k.v.a. (5570 amperes).

TABLE II—VALUES OF A SHORT-CIRCUIT AT Y WITH A BUS REACTANCE OF 2.5 PERCENT AT 16 000 K.V.A.

Tie Lines on Bus	Total		Lines Direct, Amperes	Lines through Bus Reactance Amperes
	K.V.A.	Amperes		
1 and 4	400 000	17 600	10 200	7 400
1, 2 and 4, 5 ..	673 000	29 500	18 400	11 100
1, 2, 3 and 4, 5, 6	874 000	38 300	25 000	13 300

The method of deriving these values involves only plain arithmetic, and is as follows: A feeder circuit of 8000 k.v.a. with its total reactance is brought to the basis of 100 000 k.v.a. with its equivalent reactance, and this resultant reactance is added to that of the generating station bus. Thus 8000 k.v.a. at seven percent reactance (station *A* to substation *X*) is equivalent to 100 000 k.v.a. at 87.5 percent reactance. The power from station *A* to substation *X* would then equal the power on station *A* bus, or 100 000 k.v.a. at eight percent reactance, modified by the reactance of one feeder of 8000 k.v.a. at eight percent reactance or 100 000 k.v.a. at 87.5 percent reactance. Then the total power from station *A* to substation *X* would equal 100 000 k.v.a. at 95.5 percent reactance.

In like manner the power from station *B* to substation *X* can be calculated, using 5.5 percent as the reactance of the circuit, and 100 000 k.v.a. at ten percent reactance as the power on stations *B* bus. This gives the power from station *B* to substation *X* as 100 000 k.v.a. at 78.75 percent reactance.

Then the total power on the substation bus equals that from station *A* (100 000 k.v.a. at 95.5 percent reactance or 82 500 k.v.a. at 78.75 percent), plus that

TABLE III—VALUES OF A SHORT-CIRCUIT AT Y WITH A BUS REACTANCE OF 2.5 PER CENT AT 8000 K.V.A.

Tie Lines on Bus	Total		Lines Direct, Amperes	Lines through Bus Reactance, Amperes
	K.V.A.	Amperes		
1 and 4	366 000	16 000	10 200	5 800
1, 2 and 4, 5 ..	600 000	26 400	18 400	8 000
1, 2, 3 and 4, 5, 6	775 000	34 000	25 000	9 000

from station *B* (100 000 k.v.a. at 78.75 percent reactance), giving a total of 182 500 k.v.a. at 78.75 percent reactance, or 100 000 k.v.a. at 43.2 percent reactance. 100 000 k.v.a. at 43.2 percent reactance will permit the flow of 232 000 k.v.a. into a short-circuit which would give 10 200 amperes at 13 200 volts.

With two tie lines on the substation bus, the power on the bus would be 418 000 k.v.a. (equivalent to 18 400 amperes, at 13 200 volts) station *A* supplying 193 000 k.v.a. (8500 amperes) and station *B* 225 000 k.v.a. (9900 amperes). The calculations for this would be just as described for one tie line, except that the feeder capacity from station *A* would be 16 000 k.v.a. at seven percent reactance; and from station *B*, 16 000 k.v.a. at 5.5 percent reactance. The same line of reasoning applies for any number of feeders. Fig. 2 shows diagrammatically the values for six feeders, and Table 1 gives the results for one to six tie lines.

REACTANCE IN SUBSTATION BUS

As a means of reducing the values in Table I a reactance can be placed in the substation bus, as shown in Fig. 3. This scheme will be referred to as scheme *II*, the one shown on Fig. 1 being scheme *I*. In this case two tie lines will be considered at a time, one in each section of bus.

With a bus reactance of 2.5 percent at 16 000 k.v.a. and two tie lines operating (*1* and *4*), a short-circuit on the bus at *Y* would develop 400 000 k.v.a. giving 17 600

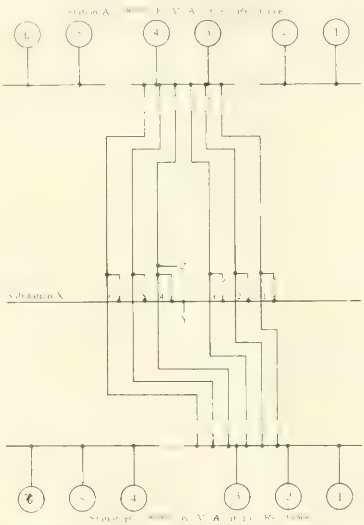


FIG. 5—(SCHEME III) SINGLE LINE DIAGRAM OF SYSTEM WITH REACTANCE BETWEEN BUS AND TIE LINES

amperes. Of this amount line *1* would send through the bus reactance 100 000 k.v.a. at 58.8 percent reactance (= 74 000 k.v.a. at 43.2 percent reactance), line *4* supplying 100 000 k.v.a. at 43.2 percent reactance. This gives a total of 174 000 k.v.a. at 43.2 percent reactance (100 000 k.v.a. at 25 percent reactance) which, in a short-circuit, would allow 400 000 k.v.a. as given above. Line *1* would supply to the right section of the bus 100 000 k.v.a. at 43.2 percent reactance. The bus reactance (16 000 k.v.a. at 2.5 percent or 100 000 k.v.a. at 15.6 percent reactance) added to this would give 100 000 k.v.a. at 58.8 percent reactance as the amount of power supplied to the left section of the bus by line *1*. Table II shows the results obtained with two, four and six lines.

An inspection of Table II shows that with two tie lines on the bus the short-circuit current (17 600 am-

peres) is not much less than for two lines with no reactance in the bus (18 400 amperes) as given in Table I. Results with four and six lines follow this ratio very closely, showing that little is accomplished by using a reactance of 2.5 percent at 16 000 k.v.a. In other words, using this reactance would mean an extra cost of bus structure to accommodate it, plus the cost of the reactors themselves, and this extra cost, extra floor space etc. produces a reduction in short-circuit current of only about 4.5 percent. Obviously then, this size reactance cannot be considered seriously.

If the reactance just considered is doubled, making it 2.5 percent at 8000 k.v.a. (5 percent at 16 000 k.v.a.) conditions would be only slightly improved over those shown in Table II as will be seen from Table III. Fig. 4 shows in a schematic way the power from six lines.

From Tables II and III it is apparent that a reactance in the bus does not reduce the short-circuit values enough to justify the expense incurred. The lines directly connected to the bus will always supply their full current regardless of this reactance, and it is this fact that keeps these currents so high. The other lines must

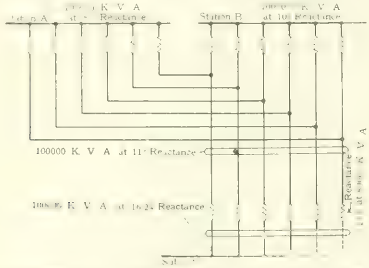


FIG. 6—(SCHEME III) SHORT-CIRCUIT CAPACITIES WITH REACTANCES BETWEEN THE SUBSTATION BUSSES AND THE TIE LINES

supply their current through the bus reactance, but this reactance is rather small when compared with the total reactance in the cables, reactors, and generators—a reactance of 2.5 percent at 8000 k.v.a. would still allow the passage of 9000 amperes with six lines. Thus, with six lines operating, the three lines directly connected to the bus would be supplying 25 000 amperes, so that a few thousand amperes through the reactance, added to this, make a sum well approaching the limits obtaining when no reactance is used. In view of these figures, scheme *II*, even with a reactance of 2.5 percent at 8000 k.v.a. is hardly worth considering as a current limiting scheme.

It would be possible to cut down this current very considerably by having the substation bus in three sections, with two tie lines per section and bus reactances between sections, similar to the arrangement indicated for station *A*. This, however, would make a rather elaborate layout for a substation, and would hardly be considered for such work.

REACTANCE BETWEEN TIE LINE AND BUS

As a further means of reducing short-circuit currents, reactances may be inserted between the tie lines and the bus, as indicated on Fig. 5 (scheme *III*). With this arrangement, using a reactance of 2.5 percent at 16 000 k.v.a. and one tie line on the bus, a short-circuit on the bus would develop 170 000 k.v.a. = 7400 amperes. This is obtained as follows. The capacity of one tie line to the substation equals 100 000 k.v.a. at 43.2 percent reactance. The reactance between the tie line and the bus, equals 16 000 k.v.a. at 2.5 percent (100 000 k.v.a. at 15.2 percent). The total capacity at the bus then equals 100 000 k.v.a. at 58.8 percent reactance, which would allow a short-circuit value of 170 000 k.v.a. or 7400 amperes.

This current is the same as that sent through the bus reactance (16 000 k.v.a. at 2.5 percent reactance) by one tie line under scheme *II*, as shown in Table I, last column. Table IV gives the results obtained with from one to six tie lines on bus.

If in the scheme just outlined the reactance is increased, making it 2.5 percent at 8000 k.v.a. instead of 2.5 percent at 16 000 k.v.a., a further reduction is obtained, as shown in Table V. Fig. 6 shows diagrammatically the results using six tie lines, with a reactance of 2.5 percent at 8000 k.v.a.

TABLE IV—REACTANCE (2.5 PER CENT AT 16 000 K.V.A.) BETWEEN TIE LINE AND BUS

Tie Lines on Bus	K.V.A.	Amperes	Equivalent Power on Bus	
			K.V.A.	Percent Reactance
1	170 000	7 400	100 000	58.8
2	315 000	13 800	100 000	31.7
3	440 000	19 300	100 000	22.7
4	552 000	24 200	100 000	18.15
5	650 000	28 500	100 000	15.43
6	735 000	32 200	100 000	13.6

TABLE V—REACTANCE (2.5 PERCENT AT 8000 K.V.A.) BETWEEN TIE LINE AND BUS

Tie Lines on Bus	K.V.A.	Amperes	Equivalent Power on Bus	
			K.V.A.	Percent Reactance
1	134 000	5 800	100 000	74.45
2	253 000	11 500	100 000	39.5
3	346 000	15 200	100 000	28.9
4	453 000	19 600	100 000	22.05
5	540 000	23 700	100 000	18.55
6	618 000	27 000	100 000	16.2

DISCUSSION OF THE VARIOUS SCHEMES

Although many systems may have six tie lines between generating stations, very few substations will be found in actual practice that require as much as the six lines could deliver. This being the case, an operating company, although bringing the six lines into the substation, would hardly connect more than four to the bus at one time. During switching operations all six lines might be on the bus, but this condition would last for only a few minutes. This arrangement would give all the flexibility of six lines, and by limiting the number on the bus at one time to four, the short-circuit currents to be handled would be reduced approximately 30 percent. Actual operating conditions will then be more nearly approximated by assuming a total of four lines on the bus.

The short-circuit values given are for bus short-circuits, but none of the tie line circuit breakers would

have to rupture all of this current. If a short-circuit occurs on an outgoing 13 200 volt feeder, say at the beginning of the cable, this would be essentially the same as a bus short-circuit and the feeder circuit breaker would have to rupture the total amount shown. In case of trouble on one of the tie lines the circuit breaker on the damaged line would have to rupture all the current that the remaining good lines could supply into the fault.

In an earlier paragraph, it was assumed that by the time a circuit breaker could open, all dissymmetry in the short-circuit would have disappeared, and values were accordingly given for symmetrical short-circuits. This is probably satisfactory, so far as the circuit breakers are concerned, but this assumption does not necessarily hold for the stresses on the bus supports, etc. In order then to be on the safe side these stresses should be calculated as coming from unsymmetrical short-circuits, when the current will be just double (1.8 would probably be more nearly correct) the amounts shown in the tables. In figuring these stresses it is assumed that the distance between the centers of busses, with the three

TABLE VI—COMPARISON OF SCHEMES

	Scheme I		Scheme II		Scheme III	
	K.V.A.	Amps.	K.V.A.	Amps.	K.V.A.	Amps.
Short-circuit on bus	700 000	30 700	600 000	26 300	453 000	19 600
Short-circuit on tie line	573 000	25 000	410 000	18 200	166 000	7 300
*Force on bus support.	668 lbs.		488 lbs.		288 lbs.	

busses in a plane is 18 inches and that the distance between the bus supports is four feet. Then the force per foot of bus will be obtained from the formula*

$$F = \frac{8.08 I_s^2 \times 10}{S}$$

where I_s = the three-phase short-circuit current and S = the distance between centers of busses in inches.

Then with the arrangement indicated in Fig. 1 (scheme *I*) with no reactance at the substation, and four lines on the bus, a short-circuit gives (Table I) 700 000 k.v.a. = 30 700 amperes. Doubling this amount to allow for the maximum effect of unsymmetrical short-circuits, the force per foot length on the bus would be

$$F = \frac{61\,000^2 \times 8.08 \times 10^{-7}}{18} = 167 \text{ lbs. per foot.}$$

With supports four feet apart, the force on each support would be 668 lbs. In case of a short-circuit on one of the incoming lines, its circuit breaker would have to rupture the current supplied to the fault by the three good lines, 573 000 k.v.a., giving 25 000 amperes (see Table I).

When using scheme *II* (Fig. 3) with four lines on the bus, and a bus reactance of 2.5 percent at 8000 k.v.a. a short circuit will develop (Table III) 600 000 k.v.a. = 26 300 amperes, and the force on each bus support will equal 488 lbs.

In the event of a short-circuit on the tie line at *Z* its circuit breaker must rupture 410 000 k.v.a. = 18 200 amperes. Of this amount, the line directly connected to the bus (say No. 5) would supply 10 200 amperes. (See Table I for one line) and lines *1* and *2*, (100 000 k.v.a. at 55.15 percent reactance) would supply 181 000 k.v.a. = 8000 amperes.

Again using scheme *III* (Fig. 5), with the reactance the same as above for scheme *II* (2.5 percent at 8000 k.v.a.) and four lines on the bus, a bus short-circuit gives 453 000 k.v.a. = 19 600 amperes and the force on each bus support will equal 288 lbs.

If a short-circuit occurs on a tie line at *Z* its circuit breaker will be called upon to open 166 000 k.v.a. or 7300 amperes. The reason for this low value is that the power from the other three lines must pass, not only through their own individual reactances, but after they are in parallel on the bus, through the reactance of the damaged line as well. The fact that the duty on these circuit breakers can be reduced from 25 000 amperes, (scheme *I*) to 7300 amperes by using scheme *III* would, in itself, make scheme *III* worthy of serious consideration.

Table VI shows the comparative results for the three schemes. In each case four lines are considered, and a reactance of 2.5 percent at 8000 k.v.a. is used in schemes *II* and *III*. This table shows that the use of scheme *III* reduces the bus short-circuit from 30 700 amperes (scheme *I*), or 26 300 amperes, (scheme *II*), to 19 600 amperes—a reduction of practically 40 percent over scheme *I*. The duty on an incoming line circuit breaker in case of a short-circuit on a tie line will be cut down from 25 000 amperes (scheme *I*); or 18 200 amperes, (scheme *II*), to 7300 amperes—a reduction of 70 percent over scheme *I*. Likewise the force on each bus support would shrink from 668 lbs. (Scheme *I*), or 488 lbs. (scheme *II*), to 288 lbs.—about 44 percent as much as under scheme *I*.

Reducing the rupturing duty on the oil circuit breakers 40 percent means that a circuit breaker of lower rating can be used. Naturally this circuit breaker would be smaller, resulting in a lower cost, and would allow a less expensive type of 13 200 volt bus structure, one that takes up less floor space, has less height, and uses smaller bus supports. Obviously, then, real good can be accomplished by this means.

Scheme *II* has two advantages over scheme *III*, better voltage regulation on the bus, and lower cost of the reactances. With scheme *II*, assuming that the load on the two bus sections is the same, the bus reactance will have no effect on the voltage regulation, as there will be no current over this reactance. Also, scheme *II* requires only one set of reactance coils, while scheme *III* would require six sets. It is felt, however, that the advantages gained by use of scheme *III* will more than offset its disadvantages and scheme *III* certainly seems the most feasible of the various plans discussed under the conditions assumed.

*See article on "Repulsion between Bus-Bars", by S. G. Leonard and Chas. R. Riker in the JOURNAL *for* Dec. 1917, p. 491, and paper by I. W. Gross in *Proc. A.I.E.E.*, Vol. XXXIV, p. 23 (Jan. 1915).

Essentials of Transformer Practice-XIX

Operating Conditions

E. G. Reed

IN SERVICE, transformers are subject to a number of operating conditions which are serious in that at times they interrupt the continuity of service. By observing the proper precautions, some of these troubles may be entirely eliminated and others may be minimized. A detailed study of some of these difficulties is important in suggesting improvements in manufacture, and to indicate when a change in the operating condition is desirable.

OVERLOAD

For distributing transformers the conditions of service are such that failures from overload are likely to occur. Since the maximum load exists for only a few hours daily, the tendency is to increase the maximum value of the load beyond safe limits, the transformers either being unprotected or being fused so that a heavy overload is permitted. A transformer burn-out often obliterates the evidence of the cause, and erroneous conclusions are difficult to avoid. However, in case of failure from overload, the windings are usually reduced to a mass of copper wire and charred insulation.

About eighty percent of the distributing transformers which burn out are below 7.5 k.v.a. in capacity, and of these about sixty-five percent fail from overload, twenty percent from water penetrating the windings and fifteen percent from short-circuits due to lightning and other causes.

SHORT-CIRCUITS AND GROUNDS

Short-circuits and grounds are usually due to lightning surges, to the presence of water in the transformer, to the wires working against each other when the windings expand and contract under varying conditions of load, or to the mechanical shocks to which the windings are subjected by short-circuits on the line. A short-circuit in service, say in the high-voltage winding, causes a large current to flow in the short-circuited part, which acts as a secondary carrying a large current, and draws an abnormally large current through the remainder of the primary winding. Thus the short-circuit starting in the primary winding may or may not spread through the entire coil, depending on the way the transformer is protected with fuses. The primary winding may be practically destroyed and the secondary coils remain in fairly good condition, and for this reason it usually is possible to distinguish between a short-circuit starting in the primary winding and a general roasting by overload. If the short-circuit starts in the secondary winding, the trouble is more likely to be localized in that part, as the immediate results of the short-circuit are more violent; and the primary coils may not be injuriously heated, depending on the completeness of the fuse protection. With a transformer of fairly large size the short-circuit is usually localized, and the transformer is cut out by the protecting device before the trouble has extended throughout the windings.

Before they are installed, transformers are sometimes stored in damp places, where they collect sufficient moisture inside of the cases to become visible, and bright metal parts like the heads of screws may become rusty. Water also gets into transformers by the so-called breathing action, which continually takes place with changes in load, particularly in damp localities, or may be put in with the oil. The higher the voltage of the transformer the greater is the probability that a given amount of moisture will cause trouble. However, it is surprising how much water a comparatively low-voltage transformer may accumulate in service, and still continue to operate. It is not uncommon to find a considerable amount of water in the bottom of a transformer when it is operating satisfactorily. The heat generated within the coil does not permit the water to penetrate to a vital point, but if the transformer is allowed to cool and then put on the line again, the water may have penetrated sufficiently to cause an immediate failure. Therefore, if a transformer is put into service and a failure does not occur at once, a later breakdown due to moisture is not to be expected unless the conditions become very much worse. Where a short-circuit is started by moisture, the most superficial dielectric strength tests on some of the insulating material will confirm its presence. When a transformer is suspected of having absorbed moisture, although it may not be actually visible, a comparison of its insulation resistance with that of a dry transformer will indicate its actual condition. When moisture is known to be present, the only safe procedure, particularly if the transformer has a relatively high voltage, is to dry it out before it is installed.

DRYING OUT TRANSFORMERS

Relatively large masses of insulating material are used between high and low-voltage windings and between windings and iron. When moisture is present throughout the transformer, the drying out process is slow because the moisture must be drawn out through this material. Transformers are usually dried by short-circuiting the low-voltage terminals and impressing such a voltage on the high-voltage leads as will circulate sufficient current to heat the coils gradually to a temperature by thermometer of about eighty-five degrees C. Ordinarily currents less than normal full load, depending on the size of the transformer, are required; for example, with the larger sizes, say above ten k.v.a. the current required will be relatively smaller than for a one k.v.a. unit, the temperature by thermometer being

the guide to the permissible current. Usually the applied voltage will be less than three percent of the normal voltage of the winding to which it is applied, as the average impedance is in the neighborhood of three percent.

When the insulation resistance measurements indicate that the insulation from the high-voltage windings to ground is dry, it is fairly certain that the remaining insulation in the coils is also dry. A single insulation resistance measurement will not indicate definitely whether a transformer is sufficiently dry. A fairly reliable indication is given by a series of resistance readings taken during the drying run, plotting resistance values as ordinates and time as abscissae. Even then there is no definite knowledge of the point on the curve where danger ends and safety begins. There is a rather wide range between the minimum safety value and the maximum value of the insulation resistance, but the drying should be continued until the curve tends to become flat at a considerable elevation above its lowest part. This will require several hours on small units and a longer time with larger units. Where there is much moisture present, the curve will remain flat for a considerable period before starting to rise.

After having been soaked in oil, a transformer will have a lower insulation resistance than the same transformer without the oil. When oil is present, the rising of the curve when drying is due to getting rid of the oil in the form of vapor as well as to the removal of the moisture. When the curve is carried to a high point, both the oil and the moisture must be driven out, which takes a much longer time than if the oil was not present.

CARE OF INSULATING OIL

Oil in large quantities is generally shipped in tank cars, which are usually lagged to prevent rapid fluctuations in temperature during transit. This reduces the effect of expansion and contraction of the oil, with its resultant absorption of moisture. Oil is also shipped in steel barrels or drums with screw bungs, which are sealed before shipment. Such barrels should be packed on their sides with the screw bungs down. Small quantities of oil are shipped in soldered cans which are sealed before shipment. Every precaution should be taken in the shipment of oil to prevent absorption of moisture.

In spite of the precautions taken to make the containers tight, oil in drums or cans should not be stored in the weather, and oil drums should not be stored on end. Such a position allows water to collect in the head around the bung, and under such conditions even the tightest tank will allow water to enter. If possible, oil should be stored in a closed room, but if it is necessary to store it out doors, protection from the weather should be provided. Cans or barrels should not be unsealed before the oil is needed, as any change in temperature will cause an exchange of air in the receptacle with danger of precipitation of moisture into the oil.

During the transfer of the oil from the drums to the apparatus, care should be taken to prevent any moisture or dirt getting into either. A drum of cold oil when taken into a warm room will "sweat" and the resulting moisture on the outer surface may mix with the oil as it flows from the drum. Before breaking the seal the drum should therefore be allowed to stand long enough to reach room temperature. All vessels used for transferring the oil should be inspected to see that they are dry and free from dirt. Foreign material, such as scale from iron barrels, may become dislodged during shipment; or if the apparatus is installed, for example, near cement mills, dust may enter the oil and reduce its dielectric strength.

Oil which has not been put through a filter press should be strained through two or more thicknesses of muslin or other closely woven cotton cloth, which has been washed and dried to remove the sizing. The straining cloths should be renewed as often as necessary, and not less than one set of cloths should be used for one transformer. Metal hose is preferable to rubber hose because the oil may dissolve the sulphur contained in the rubber. Oil should preferably be transferred from its container to the apparatus in dry weather. If it is necessary to do this in wet weather, the transfer should be made indoors to prevent the possible access of water. Before the apparatus is filled the oil should be sampled and tested. After the apparatus is filled with oil, it should immediately be covered and then allowed to stand sufficiently long to allow the oil to penetrate the apparatus. It should then be inspected and refilled to the proper oil level, if this has been appreciably lowered, and the cover be immediately tightened in position.

MECHANICAL STRESSES ON SHORT CIRCUIT

Due to the low reactance of transformers, a short-circuit on the secondary side would theoretically permit from twenty to fifty times full-load current to circulate through the windings, depending on their impedance, provided the supply system has sufficient capacity. Since the mechanical forces* on the windings, set up electromagnetically, vary as the square of the current, the forces may be sufficient under certain conditions to distort the windings and destroy the insulation not only between the conductors but also between the high and low-voltage windings. To avoid failures of this kind the transformers should be thoroughly protected by fuses or circuit breakers, the windings be so thoroughly braced as to withstand the shocks of short-circuit or the impedance be made high enough to limit the current on short-circuit to safe values. Under actual operating conditions, transformers are seldom installed where the regulation of the source of supply, assuming that no circuit breaker or fuse protection is used, is such that the extreme current values just referred to actually occur. This is particularly true regarding distributing transformers, where the regulation

*See also an article on "Mechanical Stresses in Transformers" by J. F. Peters in the JOURNAL for Dec. 1915, p. 555.

of the distributing lines will greatly reduce the voltage impressed on the transformer under short-circuit conditions.

The direction of the forces between the primary and secondary winding of a concentric transformer winding is shown in Fig. 1. The mechanical force between these two coils is due to the leakage field between them, which has been discussed in section IV. From equation (1) of section IV, the flux density of the leakage flux in the gap between the coils in gausses, is

$$B = \frac{4\pi}{10}\,\frac{IT}{l}$$

Where IT is the ampere turns in the winding and l is the average length of the leakage path in centimeters. Expressing the value of B as a maximum, gives,

$$B = \sqrt{2}\,\frac{4\pi}{10}\,\frac{IT}{l} \quad \text{. . . . . (1)}$$

Since the magnetic flux density in the outer coil for example is a maximum on the edge adjacent to the gap between the coils and is zero at the outer edge, the average value of the density in the coil is,

$$B = \sqrt{2}\,\frac{2\pi}{10}\,\frac{IT}{l} \quad \text{. . . . . (2)}$$

The force in dynes acting on a conductor carrying current when in a magnetic field is,

$$F = \frac{B\sqrt{2}\,I\,T\,l_m}{10} \quad \text{. . . . . (3)}$$

Where I and T have the same values as before and l_m is the length of the mean turn of the conductor when wound into a transformer coil. Combining equations (2) and (3) gives,

$$F = \frac{4\pi}{100}\,\frac{(IT)^2\,l_m}{l} \quad \text{. . . . . (4)}$$

Assuming that I has a sine wave form, then F is a sine² function and the average force over one-half cycle is one-half of equation (4), or

$$F_{ave} = \frac{2\pi}{100}\,\frac{(IT)^2\,l_m}{l}$$

Where l and l_m may be expressed either in inches or centimeters. Expressing the force in pounds,

$$F_{ave} = \frac{1.41}{10^7}\,\frac{(IT)^2\,l_m}{l} \quad \text{. . . . . (5)}$$

The force on the inner coil is towards the center, and is therefore one of compression. The force on the outer coil is away from the center and is therefore one of tension. If the electrical centers of the primary and secondary coils coincide, there is no force tending to move the coils in a direction parallel to their axis, and therefore no necessity for bracing against end thrust. If the coils are rectangular, the force between coils tends to force the outer coil into a cylindrical shape.

Example—What is the force in pounds between the primary and secondary coils of a 100 k.v.a., 2300 to 230 115 volt, 60 cycle, core type transformer, which has the following constants? The coils on each leg of the magnetic circuit, are arranged in a single high-low group.

$I = 436$ *amp.* $\qquad l_m = 33$ *in.*
$T = 12$ $\qquad l = 10$ *in.*

From equation (5),—

$$F_{ave} = \frac{1.41}{10^7}\,\frac{(436 \times 12)^2 \times 33}{10} = 12.7 \text{ pounds}$$

Assuming that the transformer was not protected by circuit breakers or fuses, that its impedance was five percent, and that the source of supply had a perfect regulation, the current on short-circuit would be $\frac{100}{5}$ or 20 times normal. The force between the coils would be $20^2 \times 12.7$ or approximately 5100 pounds. Actually, due to the regulation of the source of supply and of the distributing lines, the current would be something like 10 times normal, and the force between the coils $10^2 \times 12.7$ or 1270 pounds.

When the electrical centers do not coincide, the mechanical force tending to separate the primary and secondary coils can be resolved into two components, one radial and the other parallel to the axis of the coils.

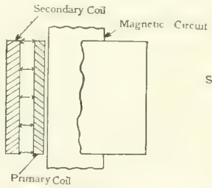


FIG. 1—MECHANICAL STRESSES BETWEEN PRIMARY AND SECONDARY

In a concentric transformer winding.

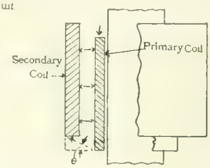


FIG. 2—MECHANICAL STRESSES

When the primary and secondary windings are displaced axially.

It requires only a slight shifting of these centers to produce a large force tending to move the coils in a direction parallel to their axis. With the electrical centers shifted as shown in Fig. 2, the total force will be as shown by equation (5), but will be distributed as follows:—

$$\left.\begin{array}{l}\textit{The radial force} = F_{ave}\cos\theta \\ \textit{The end thrust} = F_{ave}\sin\theta\end{array}\right\} \quad \text{. . . . . (6)}$$

Example—Suppose that in the preceeding example that the electrical centers of the coils had become displaced in an axial direction a distance of 0.5 inch, and that the radial distance between the centers was 2 inches, then

$\cos\theta = 0.97$
$\sin\theta = 0.24$

The forces under normal conditions are:—

In the radial direction, $12.7 \times 0.97 = 12.3$ *pounds.*
In the axial direction, $12.7 \times 0.24 = 3.2$ *pounds.*

The forces under short circuit are:—

In the radial direction, $1270 \times 0.97 = 1230$ *pounds.*
In the axial direction, $1270 \times 0.24 = 320$ *pounds.*

Electrically-Driven Plate Mills

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General Steel Mill Engineer,
Westinghouse Electric & Mfg. Company

In the selection of apparatus to drive a plate mill, the problems which directly concern the electrical engineer are the size and type of motor, control and flywheel. These three factors must always be considered as a unit, as a proper selection of any one cannot be made without a knowledge of the characteristics of the other two.*

The most common type of plate mill now installed is the Lauth 3-high mill, in which the top and bottom rolls are driven from the pinion housing, and the middle roll, which acts as an idler, is approximately two-thirds the diameter of the outside rolls. The driving shaft is connected to the middle pinion, which is also approximately two-thirds the diameter of the top and bottom pinion, so that although the speed of the outside rolls is from 50 to 60 r.p.m., the speed of the driving shaft is about 80 r.p.m. Fig. 1 illustrates the type of mill in which the flywheel and motor are directly connected to the mill. At times, a higher speed motor is selected, which is connected to the flywheel shaft through a set of herringbone gears or to the mill by means of a rope drive. An 83 r.p.m. motor is rather objectionable, particularly on 60 cycles, due to its poor electrical performance and multiplicity of coils, as such a motor requires something like 800 coils in its primary winding. If gearing is used, a standard motor can be used, any difference in speed desired being obtained by adopting a suitable gear ratio.

A plan view of the same type of mill is shown in Fig. 2, except that a Kennedy pinion housing is used, which provides a gear ratio between the driving pinion and the two driven pinions of approximately four to one. With this scheme, the motor and flywheel can be operated at approximately 200 r.p.m., which makes it possible to obtain the flywheel effect with a much smaller wheel than with the scheme shown in Fig. 1. It also permits the use of a motor having better electrical performance.

There has recently been a tendency to install tandem sheared plate mills, thus breaking the slabs down in one stand and making the finishing passes in another. There are a number of three high tandem mills now installed in which the methods of drive outlined in Fig. 1 and Fig. 2 are used. A modification of this scheme is to use a direct-current reversing motor connected directly to the bottom pinion of the roughing stand, in which case an Ilgner set is used to supply power to the reversing motor. This makes it possible to adjust the speed of the roughing rolls carefully to suit the slab being rolled. During the first passes, the speed can be kept low, so that the slab is not thrown on the tables in such a way as to require manipulation after each pass. On a three high mill, the intervals between passes are seldom less than three seconds, and more when the piece is manipulated. On a reversing mill, the metal can be handled so that it is always under control and very much less manipulation is required. The intervals between passes are often as short as one second, and as the intervals form a large percentage of the total time during the early passes, an appreciable saving in time is effected. The cost of the electrical equipment is naturally greater, but the mill itself is simplified in that it is only two-high, tilting tables are not required, and the cost of the flywheel is included with the electrical apparatus, as it is a part of the Ilgner set. The finishing stand is three-high, and is driven by a constant speed motor; the method of drive may be similar to that shown in either Fig. 1 or 2.

The majority of the universal mills are two-high reversing, the driving unit being connected directly to the bottom pinion. The method of drive is similar to that shown on the roughing stand of Fig. 3, with the vertical rolls added.

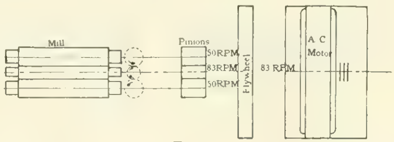

Fig. 1

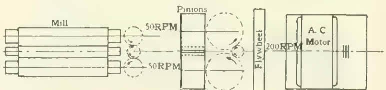

Fig. 2

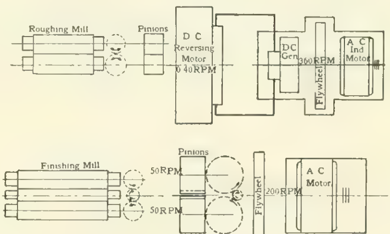

Fig. 3

FIGS. 1, 2 AND 3—TYPICAL STEEL MILL DRIVES

NATURE OF LOAD

A number of tests have been made on electrically-driven plate mills so that it is possible to predict the power requirements with a fair degree of accuracy. These calculations should be used as a guide in selecting the flywheel, motor and type of control. In Figs. 4, 5, and 6, are sample load curves which have been developed from actual tests. Such curves can be prepared from calculated results, but these particular ones are prepared from actual tests, each being made on a separate mill. From these curves, it will be seen that the power required at the mill is of a highly intermittent character, which makes it important to utilize flywheel effect.

*Revised by the author from a paper before the Philadelphia Section of the Association of Iron and Steel Electrical Engineers.

TYPES OF CONTROL

In Fig. 4 is shown a load curve of a mill driven by a wound-rotor induction motor, having a permanent resistance in its secondary at all times. With this type of control, the speed of the motor drops off in direct proportion to the load. In other words, if the mill is operating light, any increase in load would cause the speed of the motor to decrease in proportion to the amount of external slip resistance. This scheme does not utilize the flywheel to its best advantage, as the flywheel should not be called upon to give up energy until the motor has first been loaded. The ideal condition would be to have the speed of the equipment remain at light load speed until the motor is carrying full load, and any load beyond this value should be taken by the flywheel. The flywheel is installed as reserve capacity, and its energy should be conserved as long as the motor is not loaded.

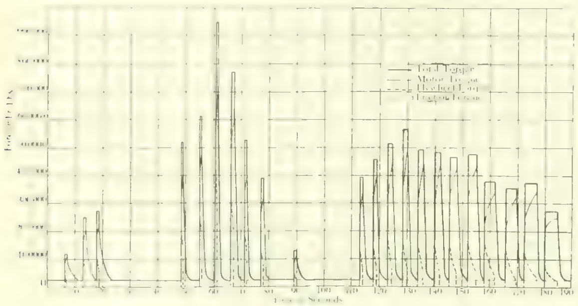

FIG. 4—TORQUE CURVE OF INDUCTION MOTOR WITH A FIXED SECONDARY RESISTANCE

Torque based on 83.3 r.p.m., rolling plate from a slab.

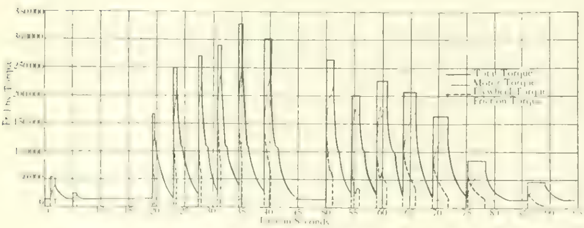

FIG. 5—TORQUE CURVE OF INDUCTION MOTOR WITH NOTCHING-IN SECONDARY RELAYS

Torque based on 83.3 r.p.m., rolling plate from a slab.

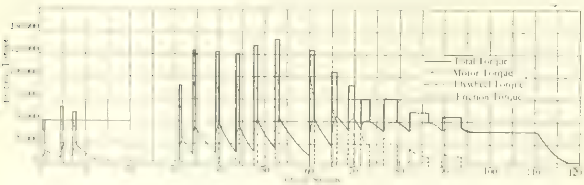

FIG. 6—TORQUE CURVE OF INDUCTION MOTOR WITH LIQUID SLIP REGULATOR

Torque based on 250 r.p.m., rolling plate from a slab.

An improvement upon this scheme is made by the use of notching-in relays. With this type of control, a permanent resistance is placed in the secondary, of about five percent. When the motor reaches its full load, additional resistance is inserted in the rotor circuit so that the flywheel is called upon to carry a greater proportion of the peak load. A number of such equipments were installed several years ago, but it was found that the additional slip resistance was not inserted quickly enough to ward off the peaks and that continual interruption of the secondary current increased the maintenance on these switches so that, as a rule, the operator arranged the control with a fixed amount of resistance in the secondary circuit. Fig. 5 graphically shows the load on a mill equipped with this type of control with the relays set to operate at 175 000 ft. lbs. torque. On the ninth pass, they did not operate until a load of 200 000 ft. lbs. torque was obtained. From an inspection of the motor torque curves during passes *4* to *8* inclusive, it would seem that the relays did not operate, but these particular passes are so heavy that the relays operated immediately upon the introduction of the metal and the initial swing of the meter was so rapid the effect of the additional slip could not be detected.

In Fig. 6 is shown a load curve on a mill driven by a wound-rotor induction motor having a liquid slip regulator in its secondary circuit. This is an improvement over the preceding schemes as it more nearly approaches the ideal condition of conserving the flywheel effect until the motor is fully loaded, and at the end of the pass, working the motor to capacity until the flywheel has been returned to its normal light load speed.

Slip curves of the three schemes outlined above are given in Fig. *7*. If a synchronous motor were operating the mill, its speed would be constant, regardless of the load and would follow the line *AB*. If the motor was a squirrel-cage or a wound-rotor induction motor with its slip rings short-circuited, it would drop off approximately three percent from no load to full load, and would follow the curve *AC*. If the wound rotor induction motor had additional external resistance to give a total of five percent slip, its operation would be as indicated on curve *AD*, and with 15 percent total slip, its operation would allow curve *AE*. If the motor has 15 percent fixed slip resistance in its secondary, the available flywheel capacity would be exhausted at the same time the motor reaches full load. The average load on the motor during the period of time the flywheel is called upon to give up its energy is approximately 50 percent. The exact average would have to be determined by the character of each individual pass. As is stated above, in order to utilize

the motor and flywheel to better advantage, notching-in relays are used. In this case, the motor would work on curve *AD*, the speed merely dropping five percent when the additional resistance is inserted and the operation would then be transferred along *DF* to curve *AE*. The way in which the load drops off when the additional resistance is inserted in the secondary, can be noted from passes *9*, *10* and *11* of Fig. 5.

The liquid regulator type of control was introduced to maintain the flywheel speed until the motor is actually over-loaded. With this scheme of control, the operation of the motor is on curve *AC* until full load is obtained, at which time the motor remains in operation at full load and the speed drops from *C* towards *E*. At the end of the pass, the motor still continues to operate at full load, the speed increasing from *E* to *C* and then the load drops off from *C* towards *A* to the friction load. In Fig. 6, the motor continued to operate at capacity for 17 seconds after the last pass. Unless there is reason to limit the load taken by the motor due to power house capacity, it would be better to adjust

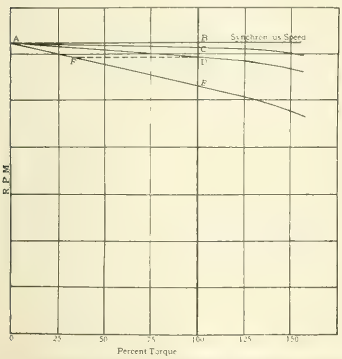

FIG. 7—SPEED TORQUE CURVES OF WOUND-SECONDARY INDUCTION MOTOR

this regulator to allow the motor to take 200 kw more, in which case, the flywheel would be brought up to speed during the last passes.

The dashed lines in Figs. 4, 5 and 6 represent the torque developed by the flywheel. In the first two figures, this torque is less than that given up by the motor and takes about the same proportion of the load, regardless of the pass. In Fig. 6, the flywheel is shown to absorb the greater proportion of the high peaks and very little of the last passes. A graphic chart taken on a 90 in. plate mill is shown in Fig. 8. The part having uniform peaks of 2000 kw shows the operation of the liquid regulator. The motor secondary was then transferred to magnetic control with resultant irregular peaks, some going off the scale at 3600 kw.

From the performance of the liquid regulator, it is apparent that it is best suited for plate mill applications and can therefore be selected, regardless of the method of drive, whether the motor and flywheel be direct connected or geared. With this feature settled, the next point for consideration is the size and method of connecting the motor and flywheel to the mill.

POSITION OF FLYWHEEL

The question often arises as to the advisability of placing the flywheel effect in the rotor of the motor. The flywheel capacity required is, of course, usually more than can be obtained by increasing the weight of a normally designed rotor. The diameter of the rotor is therefore increased, so that the peripheral speed of the rotor coils is higher than would otherwise be dictated by accepted practice for motor design. In addition to this, the design of the motor is special and unless the motor required happens to be a duplicate of one previously built, which is seldom the case, this individual motor must carry the development charge of a new machine. If it is desired to combine the motor and flywheel, a better scheme is to place a separate flywheel on the motor shaft. It is, however, important that the shaft and bearings be liberal in their design, as the air-gap of an induction motor is inherently small and any springing of the shaft or wear in the bearings will set up an unbalanced magnetic pull. By placing the flywheel on its own shaft and bearings, and using a coupling between the motor and flywheel shaft, which will permit a small misalignment, the flywheel can wear

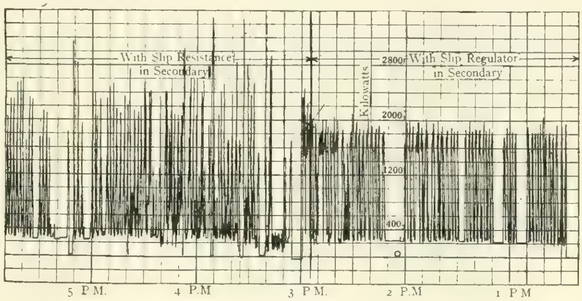

FIG. 8—GRAPHIC CHART OF LOAD ON A 90 INCH PLATE MILL

down its bearings without in any way affecting the motor. This scheme not only utilizes a standard motor, but repairs to the motor are simplified, since the flywheel can be completely isolated at the coupling.

If the flywheel is placed directly on the mill shaft, its speed will be approximately 83 r.p.m. At this speed the diameter of the wheel would be fixed by manufacturing limits, which at the present seldom exceeds 24 feet. This would result in a peripheral speed of 6250 feet per minute. If the scheme shown in Fig. 2 is used, its speed will be 200 r.p.m. Using 12 000 feet per minute as the maximum allowable peripheral speed for cast steel, the wheel in this case could be 19 feet in diameter. Operating at 12 000 feet per minute, its weight would be slightly over over-half of the 24 foot wheel running at 6250 feet per minute.

If the mill is laid out as in Fig. 1, except a 360 r.p.m. motor is connected to the mill through a herringbone gear unit, and flywheels are placed on the pinion shaft, either cast steel or plate wheels can be used. The steel wheel would be limited to a peripheral speed of 12 000 feet per minute, and the weight of a cast steel

wheel would be one-fourth that of the one required for the scheme shown in Fig. 1 and of the same weight as the wheel shown in Fig. 2. As plate wheels can be run as high as 25 000 feet a minute, the weight could be further reduced, if they are used instead of cast steel. The limitation in diameter of plate wheels in this particular case will be fixed by the size of plates which can be rolled.

The objection to placing the wheels on the pinion shaft is that all peak loads are transmitted through the gearing. Of course it is entirely possible to provide for the peaks obtained during each pass, but there will be times when an attempt will be made to roll tongs or other foreign material. With high speed wheels on the pinion shaft, something is bound to break. It is these stresses, which cannot be estimated, that make it preferable to put the flywheel as near the mill as possible, such as shown in Figs. 1 and 2.

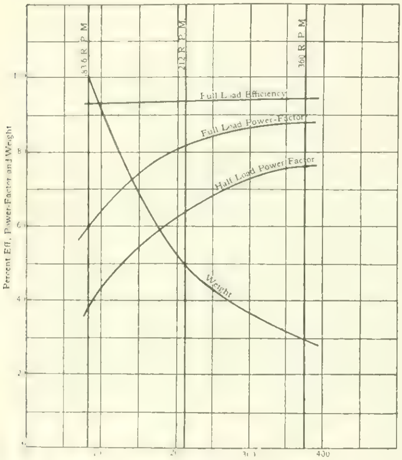

FIG. 9—TYPICAL CHARACTERISTIC CURVES OF 2000 TO 5000 HP, 3-PHASE, 60 CYCLE, 2200 VOLT INDUCTION MOTORS

POSITION OF MOTOR

The first cost of the motor will decrease as the speed is increased, and the electrical performance will be better on the higher speed machines. Fig. 9 shows graphically the variation in performance and weight of 2000 to 5000 hp, 60 cycle motors. The efficiency varies so little with speed, that it can be neglected as a factor in the selection of the drive. However, the power-factor varies over a wide range and, as will be noted from Fig. 9, it drops off rapidly at the slower speeds. The wattless components are as follows:—

R. p. m.	Full-Load Power Factor	Percent Wattless Component
83.6	60	80
212	82	57.2
360	88	47.4

The 360 r.p.m. and 212 r.p.m. motors have very fair power-factors but the 83.6 r.p.m. motor would in general require the installation of synchronous apparatus to correct the power-factor. If the motor was selected from the point of view of power-factor alone, the preference would be for one of the higher speed motors with a slight advantage in favor of the 360 r.p.m. motor, but either this or the 212 r.p.m. motor would be quite acceptable.

The weight and the cost of the 83.6 r.p.m. motor is three times that of the 360 r.p.m. motor, and twice that of the 212 r.p.m. machine. The best proposition as far as cost is concerned, can only be determined when the cost of the gearing is included with the motor for each individual scheme. In practically every case a material saving in first cost will be obtained by installing either the 212 or 360 r.p.m. motor. For an installation of this nature, the 360 r.p.m. motor and gear will cost 25 percent less than the 83.6 r.p.m. motor.

The only objection to installing the higher speed motors is the reliability of gearing. Several years ago this was rather a serious objection, but that is gradually passing as to-day there are a number of large gear units giving remarkably good service. This record is by no means universal, but the progress that is being made in the design and construction of herringbone gears will soon leave little reason for installing an expensive slow-speed motor.

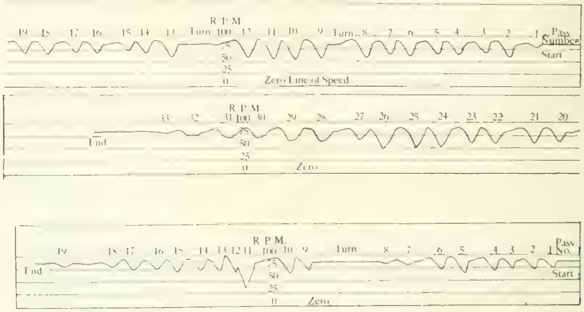

FIG. 10—SPEED CHARTS OF A TYPICAL ENGINE DRIVEN PLATE MILL

This phase of the discussion naturally refers to continuous running motors only, as two-high reversing mills similar to that shown as the roughing stand of Fig. 3 would of necessity be operated by a direct-current reversing motor directly connected to the mill, with the flywheel as a part of the Ilgner set.

ENGINE-DRIVEN MILLS

Quite often reference is made to plate mills driven by engines which have much smaller capacity than the size of motor recommended. If an engine is overloaded, it simply slows down, warning the operators, so that they will roll at a slower rate. Usually the first intimation that the operators have of an overload on a motor is the opening of the circuit breaker. This quite often leaves the metal in the rolls and is almost sure to cobble the piece. Fig. 10 shows a graphic speed curve taken on a 140 in. engine-driven mill which had been used as an instance of a satisfactory steam drive where the motor capacity recommended was larger than

that of the engine. In this particular case, a maximum drop of 60 percent and an average of 35 percent was obtained during the heavy passes. This cannot be considered good practice and it is surprising to find what increase in tonnage can be obtained when steam drive has been replaced by an adequate motor drive. In one instance, a motor was installed on a plate mill to roll 500 tons per day, which was considered to be a good record, and in the fifth month of its operation, it had rolled 800 tons in one day. On another plate mill, it was planned to roll a maximum of 12 000 tons per month and in the sixth month after the mill was placed in operation 20 000 tons were rolled. Electric drive presents great possibilities where it is desired to roll record tonnages, but the flywheel and motor capacities must not be stinted. The equipment should not only be able to roll the steel, but should do so without showing any signs of distress when rolling the severest schedules. If the operators learn that they can overload the motor, it is sometimes difficult to improve the tonnage output, as they have an opportunity to blame the electrical equipment, while if the motor has a margin the tonnage output is dependent on the men.

TABLE I—KW-HOUR CONSUMPTION AND MONTHLY TONNAGE OF MOTOR DRIVEN MILLS

Size of Mill	Motor Hp	Gross Tonnage per Month Charged Weight	Kw-Hours per Ton for Main Drive	Kw-Hrs per Ton for Auxiliary Drive
110 in. sheared	4000	20 000	18	29
90 in. sheared	2000	12 000	31.5	. .
84 in. tandem sheared	2-1600	11 500	27	. .
84 in. tandem sheared	2-1600	14 000	29	45
110 in. sheared	4000	12 000	21	. .
48 in. universal . : . . .	8000	10 000	29	12

POWER CONSUMPTION

Now that the war is over, economy of operation will receive additional attention and no doubt the operating engineer will devote just as much attention to improving the efficiency of operation as the design engineer gives to a reduction of the losses in electrical machines. Tables I and II show a comparison of power consumption on electrically-driven and steam-driven mills. The tonnage listed is based on 2240 lbs. per ton of charged weight. A better comparison can be made by comparing the power consumption on charged weight than on the finished weight, as the latter depends somewhat upon the percent scrapped, which of course does not affect the power consumption. It is true that the power consumption will vary with the average elongation of the metal, the percent of time the mill is running idle, in addition to a number of other factors, but it will be found the average practice of the same sized mills does not vary greatly, and a comparison of the power consumption per month is a much truer method than by comparing the load efficiency of an electric motor with that of a steam engine. During the time the mill is not rolling steel, the steam losses of an engine-driven mill are comparatively high and should be included. When an electric motor is shut down, its losses are nil.

The last column in Table II gives the equivalent killowatt-hours per ton on the assumption that a steam turbine would consume 20 lbs. of steam per kilowatt-hour taken by the motor on the mill. This is very liberal, particularly in plants where large turbines are used, but this figure includes the power required by the auxiliaries and transmission losses and is based on a fluctuating load on the turbine. The kw-hr. consumption for the auxiliaries of the 48 in. universal mill in Table II is low, but it includes only the tables, shears and cranes while these values for the other mills include pumps, compressors, lights, etc., in fact everything complete except the main drive. It will be noted from Table I that, although the tonnage for the same size mills may vary over a wide range, still the power consumption per ton is almost the same. This brings out the fact that electrical equipment maintains a high efficiency even when operating at low capacity. The high efficiency of an electrical motor is maintained at light load and the instant it is shut down, the losses disappear. A comparison of the two tables indicates that larger motors are placed on mills than was formerly the practice with engines, but it is also evident that considerably larger tonnages are obtained on the motor-driven mills.

TABLE II—STEAM CONSUMPTION AND MONTHLY TONNAGE OF ENGINE DRIVEN MILLS

Size of Mill	Engine	Hp	Gross Tonnage per Month Charged Weight	Steam per Ton	Equiv. Kw-Hrs. per Ton
140 in.	46 by 60	2250	13 100	1660	82.5
112 in.	36 by 60	1400	6250	3000	150
84 in.	28 by 48	730	1875	3430	171
48 in. universal	34 and 60 by 60	1500	7700	1300	65
72 in.	44 by 60	1000	4700	1300	65
84 in.	44 by 60	1000	5000	1315	66

From the power figures given, it is apparent that a considerable saving would be obtained if the engine-driven mills were replaced with electric drive. Not only would better economy be obtained, but maintenance charges would be reduced, and a greater tonnage could be expected. Problems of this type should receive considerable attention at present, and in order that we place ourselves in a position to compete for export business during the reconstruction period of Europe, the management of every plant should have before them in very definite figures, the saving and increased tonnages which would be obtained by bringing their equipment up to date.

Some Characteristics of Transformer Oils

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While refined mineral oils have been successfully employed as insulating mediums for a period exceeding 15 years, the risk entailed by their use and the factors that govern their inflammability do not appear to be generally known.

Beginning with methane or marsh gas (CH_4), the hydrocarbon group, of which transformer oil is a member, passes through a long series in which CH_3 takes the place of one atom of hydrogen, the structure of which may be represented by $C_nH_{2n} + 2$. As the molecular weights of the combinations increase, the compounds formed pass through the gaseous, liquid and solid states. Kerosene and gasolene represent the lighter, and lubricating or transformer oils the heavier liquid phase. Paraffine and its analogues are members of the solid state.

Coincident with change in molecular structure, variations are produced in specific gravity, specific heat, viscosity, volatility, dielectric strength, etc., and therefore, also in relative flash and fire points as well as insulating and cooling properties.

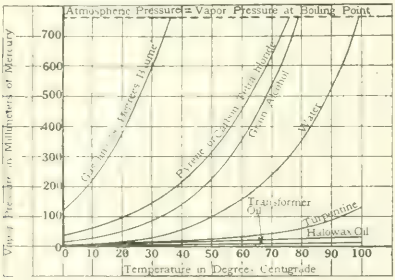


FIG. 1—APPROXIMATE RELATIVE VAPOR PRESSURES

Since hydrocarbons are inflammable under proper conditions of temperature, pressure, air mixture and ignition, their use must be safe-guarded. Fortunately, the combination of these conditions in the heavier oils is so difficult to obtain that in normal use the hazard involved is quite negligible. A convenient criterion of the inflammability of oil is the flash point. This is a definite temperature at which the vapors above an oil surface ignite without burning continuously. It is attained when the rate of evaporation is sufficient to maintain a mixture of vapor and air at the oil surface which will burn with a flash on igniting the mixture with an auxiliary flame or spark. Unless the flash point determination rigidly follows a definite procedure, the temperatures obtained may vary over a wide range. Under proper conditions of rate of temperature increase, and degree of exposure of oil surface to atmosphere, comparable data may be secured. The usual precautions to be observed are to heat the oil in a standarized cup at a rate of from five to eight degrees C. per minute in a quiet atmosphere.

As the mixture burns, the amount of vapor present rapidly decreases until combustion ceases. An appreciable interval will then elapse during which the lean mixture is enriched by further evaporation from the oil, when the mixture will again flash on ignition. On increasing the oil temperature to the fire point, the evaporation is sufficiently rapid to maintain combustion continuously. The inflammability, and explosibility of oil vapor are not peculiar to any given oil but are characteristics encountered with change in temperature of oils.

Recent tests have confirmed the conclusions drawn from the flash and fire point criteria. In Fig. 1 are compared the vapor pressures of transformer oil with those of liquids of well known characteristics. Since oils and most liquids occlude large volumes of atmospheric gases the precaution should be observed, in taking vapor pressure measurements, of removing such gases. If this is performed by vacuum treatment, care should be exercised to prevent the escape of the more volatile constituents. The transformer oils used in this test possessed the same flash and fire points after the removal of occluded gases as before.

TABLE I—LIMITS OF COMPLETE INFLAMMABILITY OF MIXTURES OF GASES WITH AIR

Gas	Percent Gas in Air	Pres. of Gas (mm. Hg.)
Gasolene	1.5 to 6	11.5 to 45
Methane	5.5 to 14	42 to 10.5
Hydrogen	10 to 66	76 to 500
Carbon monoxide	15 to 73	115 to 555

From its known flash point and inflammability characteristics, the corresponding data for transformer oil may be approximated; 2.3 to 5 percent gas in air and 17.5 to 38 m. m. pressure of gas.

The data in Fig. 1 as well as the information contained in Table I.* indicate that it is impossible to secure an inflammable mixture of the transformer oil shown in Fig. 1 at temperatures even well above the operating range, because the vapor pressures obtained are not within the range of inflammability for hydrocarbons shown in the table.

This conclusion was confirmed in an experimental apparatus in which the confined oil and air volumes approximated those representing good transformer practice. It was found, on gradually raising the oil from room temperature and intermittently passing an induction coil discharge through the mixture of vapor and air, that the gases could not be ignited below the flash point. Since the flash point is greatly in excess of the normal operating temperature of transformer oil, it is necessary only to reduce to a minimum the liability of the oil spilling or leaking over a hot surface and subsequently igniting. In such applications as the insulation of circuit breakers, in which oil is liable to be blown out and become ignited, it is obviously desirable to select an oil having a low vapor pressure and high flash point.

*Secured by the Bureau of Mines and incorporated in Technical Paper No. 150.

A further characteristic of hydrocarbons hitherto but little appreciated is the formation, on the passage of a disruptive discharge, at or below the oil surface, of gases radically different from oil vapor. The vapors arising from the oil surface as a result of a gradual increase in oil temperature and the accumulation of which forms the basis of the flash point test, are still essentially oil and subsequently condense on decreasing the temperature to resume their original character. However, the gases resulting from the disintegration of the oil molecules are permanent over ordinary temperature ranges and are present in the following approximate percentages:—

Carbon dioxide	1.17	Hydrogen	59.10
Heavy hydrocarbons	4.86	Nitrogen	10.10
Oxygen	1.36	Methane	4.20
Carbon monoxide	19.21		
		Total	100.00

This analysis indicates the presence of a preponderating quantity of hydrogen and a relatively small amount of hydrocarbons. The nitrogen and oxygen in the reaction products show the presence of 13 percent occluded air. In view of the violence accompanying the reunion of oxygen and hydrogen, as well as the fact that hydrogen is explosive in air, within a range of 10 to 66 percent, it is evident that a destructive force can readily be obtained on the ignition of an atmosphere consisting of air and decomposed oil.

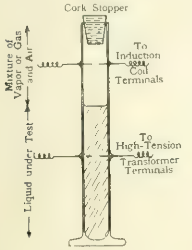


FIG. 2 — APPARATUS FOR TESTING EXPLOSIBILITY Of oil and gases and inflammability of oil vapor.

With a proportion of hydrogen to oxygen of two to one existing in the gaseous mixture, thereby assuring complete combination of both gases and most rapid reaction, the speed of flame propagation is about 11 000 feet per second, or approximately ten times that of sound waves in air. With gases initially at atmospheric pressure, an explosion would produce a pressure of eight atmospheres or about 120 pounds. Assuming the evolution of gases from an arc below oil sufficiently rapid to create a pressure above the oil, in case there is no ventilation, of 1.5 atmospheres, the maximum pressure of the explosion wave would be about 12 atmospheres or 180 pounds per square inch. As this wave, however, has a very steep front, due to its high velocity, the force applied to the structure is in the nature of an impact and the stress on the parts above the oil level may approximate 360 pounds per square inch, representing a loading sufficient to distort the container or shear the holding bolts.

Since the temperature required for the disintegration of the oil is necessarily very great, slight differences in flash or fire points of the oils used do not materially influence the ease with which such disruption is produced. No appreciable protection is, therefore, obtained by substituting a high flash for a low flash oil. In fact it has been observed that, due to the lower vapor pressure and consequent decreased dilution of hydrogen by the less active hydrocarbon vapors, explosions in the higher flash oils were occasionally more violent.

A simple device for demonstrating the explosibility of disintegrated oil gas is shown in Fig. 2. On passing a heavy discharge between the lower pair of electrodes, which are surrounded by the hydrocarbon liquid, large quantities of gas are evolved at the terminals, rise to the surface and diffuse in the air surrounding the upper pair of electrodes. On passing a weak discharge between the upper terminals a violent explosion is obtained, shattering the container or blowing the stopper out at a great velocity.

Repeated tests with this apparatus have demonstrated the explosibility of disintegration products from commercial transformer oils, as well as halowax oil (combination of hydrocarbon with chlorine) and molten paraffine. While the explosion of a mixture of air and disintegrated oil is more destructive than a mixture of air and oil vapor, it has proven to be of very rare occurrence and is always traceable to some obvious neglect. A heavy short-circuit in the transformer, sufficient to trip the circuit breakers, is of too short duration to produce conditions requisite for such an explosion. However, a partial short-circuit, continuing for a considerable period at or below the oil surface will result in the accumulation of a large quantity of hydrogen and the liability of a powerful explosion on the passage of discharges through the gaseous mixture.

To prevent such discharge and the consequent release of destructive forces, it is desirable to maintain the proper oil level above the terminal boards, thereby preventing arcing between exposed conductors, and to prevent the seepage of water over an insulated lead to the oil surface. The objections to water in transformer oil are well known. While a considerable amount of water may, by entering at the edges of the tank, flow to the bottom and accumulate without evidence of trouble until it rises high enough to be siphoned into the windings by some of the organic material acting as a wick; a very small amount of water, by spreading over the leads passing through the air chamber and eventually reaching the terminal board, may facilitate the production of streams of discharges which disintegrate the oil and then ignite the resulting mixture in a violent explosion. It is apparent, therefore, that a distinction should be made between the inflammability of gaseous mixtures obtained due to the evaporation of oil and the explosibility of mixtures obtained due to the disintegration of oil.

Since commercial transformer and switch oils have such low vapor pressures that inflammable mixtures cannot be obtained in the air space above the oil level under normal operating conditions, the first type of explosion or burning will not be readily obtained. Tests made on light oils having flash points from 125 to 135 degrees C. have shown that they will not evolve sufficient vapor to continuously support combustion until a temperature of 145 degrees C. is exceeded. This is far above any operating or room temperature encount-

ered in either a transformer or circuit breaker installation.

To prevent the occurrence of the second type of explosion every effort should be made to eliminate prolonged arcing near (above or below) the oil surface, a frequent cause being the creation of low resistance paths in the neighborhood of terminal boards by water leakage or seepage through joints and terminal leads, and low oil level. The obvious precautions are to insure the proper sealing of all joints where water may enter and the maintenance of the specified oil level.

The hazard in confined oil is, therefore, entirely due to arcing adjacent, above or below, the oil surface, while the characteristics designated as flash points and fire points are but useful indications of the hazard of scattered or spilled oil exposed in a warm atmosphere.

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country. The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

FEBRUARY 1919

Railway Motor Testing—II

ARMATURE TESTING

The tests outlined apply to standard four-pole lap or two-circuit wound 500 volt railway motors. Depending upon the size of the shop and the available source of current, testing equipment and methods of testing will vary, and with this in mind the various tests and methods, using the apparatus as described in Railway Operating Data, Jan. '19, will be outlined in general to guide the individual operator in making the required tests. Figure numbers 1 to 10 incl. refer to the January issue.

COMMUTATORS

INSULATION TESTING BOX (Fig. 1)

Short-Circuits—After the old windings are removed, the commutator should be well cleared of all solder, carbon dust, etc., and tested between bars for short-circuits, using 100 to 110 volts. In making this test, connect the testing outfit, as shown in Fig. 1, to the 110 volt lighting circuit, set the dial switch for the desired test voltage, and with the circuit breaker set and the switch closed, test adjacent commutator bars with the terminals. When the circuit breaker kicks out, a short-circuit is indicated.

Grounds—In testing for a ground, wrap a piece of thin bare wire around the face of the commutator to connect all of the bars together. Set the dial switch for 1200 volts, and with the circuit breaker set and switch closed, apply one of the testing terminals to the shaft, and the other to the commutator. If the breaker kicks out, the commutator is grounded.

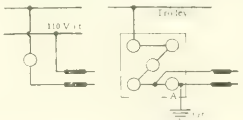


FIG. 11—110 VOLT LIGHTING-OUT LINE

FIG. 12—SCHEME FOR OBTAINING A 110-VOLT LIGHTING-OUT LINE FROM A 500-VOLT CIRCUIT

LIGHTING OUT LINE (Fig. 4)

Short-Circuits—This test can also be made by using a lighting-out line, as shown in Fig. 11, by testing adjacent commutator bars using testing terminals; when the lamp lights, the indication is that the bars are short-circuited. With the lighting-out line shown in Fig. 4, the test voltage would be 500 volts, which is too high, and is liable to injure a good commutator. A modification of this test line is shown in Fig. 12, which will give the required 100 volts. In using this modified test line, all lamps are normally lighted and when a short-circuit is located lamp *A* goes out.

Grounds—In testing for a ground with all the commutator bars short-circuited by a piece of wire, apply one of the testing terminals from the lighting-out line as shown in Fig. 4, to the shaft and the other to the commutator. If all five lamps light up, the commutator is grounded. This test is not as good as a 1200 volt test but will indicate any actual grounds.

ARMATURE COILS

INSULATION TESTING BOX (Fig. 1)

Short-Circuits between Coils—All leads are separated at both ends, and the insulation between adjacent assembled coils is tested with 100 to 110 volts, in the same manner as described for testing commutators for short-circuits.

COIL TESTING OUTFIT (Fig. 3)

Short-Circuited Turns of Single Coils—When single coils have several turns, an additional test is required as follows:—Place the assembled coil on either of the outer legs of the coil testing outfit, Fig. 3, with the yoke removed. If the wattmeter needle deflects with the exciting coil switch closed, one of the coils has a short-circuit.

In using this testing outfit, the wattmeter can be replaced by a telephone receiver. If the coil is O. K. there will be a medium buzzing sound heard in the receiver, but if it is short-circuited, the sound will be much louder. If this defective coil is placed on the middle leg of the coil testing outfit, as shown in Fig. 3, with the yoke in place and the exciting coil switch closed, the defective coil will heat and the short-circuit can be located.

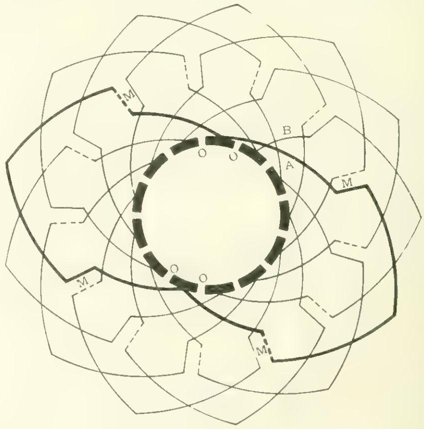


FIG. 13—CONDITIONS IN AN ARMATURE HAVING TWO ADJACENT LEADS (*A* AND *B*) CROSSED

O = Zero indication—that is, no spark with the magnetic testing yoke (Fig. 2); no sound in the telephone receiver (Fig. 5); and no reading of the voltmeter (Fig. 7).

COMPLETE ARMATURES

Grounds—When the coils are all wound in the core, and the bottom leads connected to the commutator, repeat the ground test described for commutators.

If all the coils stand the ground test, connect the top leads to the commutator bars and proceed with the following tests.

USING PORTABLE ARMATURE TESTING YOKE (Fig. 2)

In testing with this apparatus, the trouble is located by two methods, one magnetic, where a thin piece of soft iron is attracted and held against the core of the armature; the other

by a current sparking at the contact of a piece of iron short-circuiting adjacent commutator bars. In making magnetic tests, the strongest pull will be obtained on the test piece of iron when it is held on the top side of the armature core. In making sparking tests on the commutator surface, the best flashing conditions are to be found at a point on the commutator in line with the top of the iron pole of the testing yoke. All tests should be made in these locations, rotating the armature to test all coils. Some tests require only one of these methods, while others require a combination of both methods. In making routine tests, the armature core should be placed against the testing yoke with the commutator to the right of the tester, when facing the armature and testing yoke.

Reversed or Crossed Leads

Magnetic—If four slots spaced about one quarter way round the surface of the core are magnetized, this indicates a probable short-circuit, crossed or reversed coil. Reversed leads, in effect, short-circuit two coils in series, located in slots one quarter way round the armature and isolate this pair of coils from the rest of the winding, as shown in Fig. 13.

Sparking—The commutator bars connected to coils in two of these slots, located diametrically opposite to each other will give the characteristic yellow flashing spark to each adjacent bar, which indicates that they are O. K. By sparking out the commutator bars from the other two slots, two bars will be found at two opposite places on the commutator that give no spark when short-circuited to the adjacent bars on either side. These bars are connected to the reversed or crossed coils.

Short-Circuit between Coils

Magnetic—Four slots, spaced about one-quarter way around the core will be magnetized, the same as for crossed leads, as shown in Fig. 14.

Sparking—The commutator bars connected to the top coils in two of these slots diametrically opposite will give the characteristic yellow flashing spark, which indicates that they are O. K. By sparking out the commutator bars from the other two coils, two adjacent bars will be found which show no spark. The short-circuited coils are connected to these commutator bars.

Short-Circuit between Turns of Single Coil

Magnetic—If one slot only is magnetized, when the commutator is at the right, this indicates that the top coil in this slot has one or more short-circuited turns.

Sparking—No indication by this test.

Open Circuits

Magnetic—No indication by this test.

Sparking—Two adjacent commutator bars will give a bright blue spark. The same condition will be found on the two adjacent commutator bars diametrically opposite. The open circuit will be in the coil which is common to the two pairs of bars, as shown in Fig. 15.

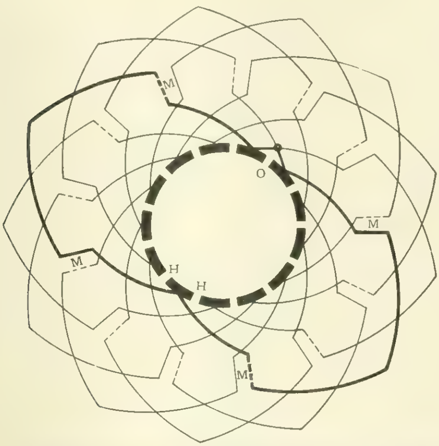


FIG. 14—CONDITIONS IN AN ARMATURE HAVING TWO ADJACENT LEADS SHORT-CIRCUITED

H = Less than normal indication. M = Magnetized Coil.

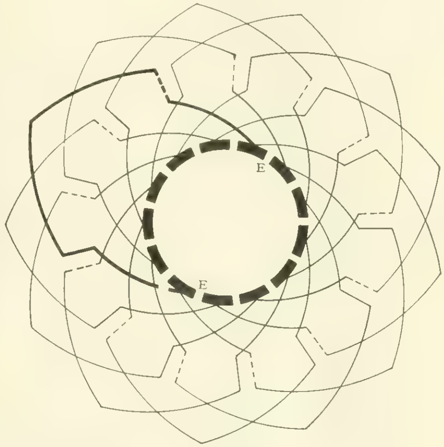


FIG. 15—CONDITIONS IN AN ARMATURE HAVING AN OPEN CIRCUIT IN ONE COIL

E = Excessive indication.

TELEPHONE RECEIVER SET (Fig. 5)

In testing the armatures with this outfit, the terminals from the battery circuit are placed on the commutator bars as shown in Fig. 5 or opened up to one fourth way round the commutator surface, and the terminals from the telephone receiver are used to test between adjacent commutator bars lying between the terminals from the battery circuit. Best results will be obtained from a telephone receiver wound for a low voltage, approximately 50 to 60 ohms; however, the ordinary telephone receiver can be used.

Reversed or Crossed Leads—Medium toned sounds in the receiver indicate that the coils are O. K., while no sounds from the two sets of two adjacent pairs of commutator bars indicate reversed or cross coils.

Short-Circuits between Coils—No sounds from the two adjacent commutator bars indicates a short-circuit between the leads or coils connected to these bars.

Short-Circuits between Turns of a Single Coil—A very faint sound from the two adjacent commutator bars indicates a short-circuit between turns of a coil.

Open Circuits—A loud sound from two adjacent commutator bars indicates an open circuit.

BAR-TO-BAR TESTING SET (Fig. 7)

In testing armatures with this outfit, the terminals from the trolley circuit (or a lower voltage circuit, if available) are placed on commutator bars as shown in Fig. 7, approximately one-quarter way around, or they can be placed closer together, as shown in Fig. 5. In order to protect the voltmeter, the resistance in the main circuit should be adjusted to give full scale deflection on the voltmeter, with an open circuit. For this reason, it may be advisable to use a higher range meter instead of the customary millivoltmeter; however, when this is done, a much smaller deflection is given while making the test observations.

Reversed or Crossed Coils—A medium deflection on the voltmeter indicates that coils are O. K. while no deflection from the two sets of two adjacent pairs of commutator bars indicates a reversed or crossed coil.

Short-Circuit between Coils—No deflection of the voltmeter indicates a short-circuit.

Short-Circuit between Turns of a Single Coil—A relatively small deflection of the voltmeter indicates a short-circuit between the turns of a coil.

Open Circuits—A full scale deflection indicates an open circuit.

NEW CENTURY TESTER (Fig. 6)

By the use of a special set of terminal attachments supplied with this outfit, all of the above tests can be made on a completely wound armature, which gives results the same as outlined when using the telephone receiver set.

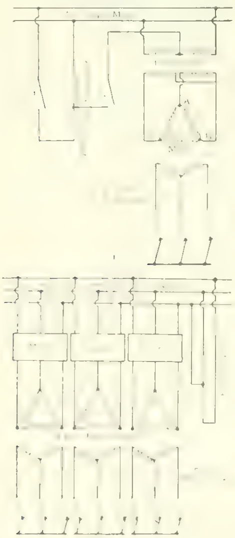
J. S. DEAN.

THE JOURNAL QUESTION BOX

OUR subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. The topics should be of general interest, information involving the specific design of individual pieces of apparatus is not supplied. Care should be used to include all data necessary for an intelligent answer.

A PERSONAL reply is mailed to each questioner enclosing a stamped, self addressed envelope as soon as the necessary information can be obtained. Anonymous questions cannot be considered. As each question is answered by an expert on the subject involved, and checked by at least two others, a reasonable length of time should be allowed before expecting an answer.

1696—THREE-PHASE MOTORS OPERATING ON SINGLE-PHASE CIRCUITS — A system of operating three-phase motors on single-phase supply systems has recently come to our notice. In practice this method seems to operate satisfactorily but we are not at all satisfied as to its efficiency. We would like to know particularly the influence this method would have on the power-factor, also the probable overall efficiency, taking into consideration transformer losses. Also please advise the respective voltages of the single-phase supply and the three-phase motor. In this method of control, one motor, usually the largest, is provided with special devices for starting up, and then, by making use of the three-phase currents set up by the interaction of the rotor current and the stator windings, the other motors are started up as three-phase motors, although running on single-phase. The motor with the special starting device thus becomes the "master" motor of the system. Although not so convenient for starting purposes as three-phase yet it is possible with very little complication to arrange three-phase motors to be started as readily on single-phase circuits as on three-phase. In order to do this the stator of a three-phase motor should be mesh connected, while the rotor should also be wound with a three-phase winding. Under these conditions, if a single-phase circuit be connected to two "corners" of the stator winding and the third corner be connected to the junction between a properly designed choking coil and resistance, a phase displacement takes place which enables the motor to start and run up to speed as the resistance is cut out of the rotor circuit. In Fig. (a) an alternating-current supply is connected to the end leads of the primary of a transformer while the middle point of the primary winding is connected to the junction of an inductive and a non-inductive resistance through switch S_2: the "phase splitter" as it is called, being connected across the mains by switch S_1. At starting both switches, S_1 and S_2, are in and a phase displacement takes place, enabling the motor to start up. The switches are then opened and the motor continues to run as a three-phase machine, although supplied with single-phase. The reaction of the current in the rotor on the stator when running induces an e.m.f. in the portion marked *BC*, so that if other motors are suitably connected to this motor they can be started as three-phase motors, providing that the motor already running has sufficient capacity. Where more than one motor has the special starting device, the first motor started becomes the master motor, and it is not necessary to use the phase splitter for the other motors since they can be started up readily when the master motor is running. When motors are fairly close together, the connections can be so arranged that by using only one phase splitter any motor can be used as the master motor for the others. This is illustrated in Fig. (b) where the phase splitter is shown permanently connected in, but can by suitable switches, be cut out of operation once a master is started up. In Fig. (b) three motors are shown, each being of the slip ring type, but squirrel-cage motors can be operated equally as well except that a starting compensator becomes necessary in order to cut down the current at starting in the case of motors above five horse-power. Where motors are fairly heavily loaded, care has to be exercised to avoid pulling those running out of step when starting larger ones, but as a general rule there is very little trouble experienced with the system.



FIGS. 1696(a) AND (b)

W.M.B. (NEW ZEALAND)

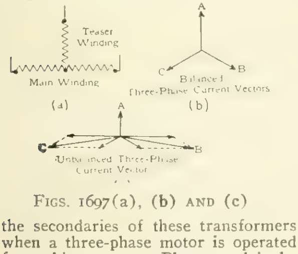
The system described dates back in its conception to 1893-95, when there was an extended discussion in the technical press of the characteristics of single and polyphase circuits and apparatus and the possibility of operating one from the other. It was at that time that the so called "monocyclic" system was advanced as a means to this end. Among other possibilities as brought out at that time is the one mentioned in this question—that it is possible to obtain a polyphase current from the windings of a polyphase induction motor operating from a single-phase circuit. Very little use has been made of this idea in the United States except in connection with railway work. This system, however, should give entirely satisfactory results in industrial work with regard to service, power-factor, efficiency etc., if the motors are chosen of proper size. A brief discussion of the starting and running conditions may be of assistance in bringing out the points to be considered and in pointing out the proper field of application for this system.

Starting Conditions—The starting of the first or so called master motor from a single-phase line by means of a phase splitter is of course subject to the handicaps of this well known starting method, namely relatively low starting torque accompanied by rather large starting currents. Therefore a motor requiring small starting torque should be chosen as master motor. The starting conditions of the next motor are considerably better and more closely approach those of a polyphase motor, the larger the master motor relative to the motor to be started; the starting conditions for the third motor are again better, etc. It thus follows that the master motor should be chosen as large as possible; also that the smallest motors as well as such motors as require a relatively large starting torque should be preferably started last. In fact the principal advantage of the system is that it permits the starting of some of the motors with better starting conditions than could be obtained if the pure split phase method of starting were used for all of them. Thus if all the motors are alike and start with the same load, there is not much to be gained by the system, unless an extra, light running motor is provided which is started first and then merely serves as a phase converter for the other motors.

Running Conditions—The running conditions of the motors are entirely governed by their relative internal drops, which in turn are principally governed by their relative size, load and speed; the internal drops are usually the larger, the smaller the motor, the heavier it is loaded, and the lower its synchronous speed. If the motors are all alike and loaded alike the drops are alike and they will simply run as single-phase motors; the third leads, while interconnected, will carry no currents. Therefore all the motors will have to be large enough to carry their load as single-phase induction motors; their power-factor and efficiency are the same as if they were independently operated single-phase. In other words, the interconnection of the third terminals does not affect the operation at all. If the internal drops are different on account of different size, speed or load of the motors, the motors with the smaller drop will supply current from their third terminal to that of the other motors. The motors re-

ceiving such current thus operate partly polyphase, which naturally improves their heating conditions, efficiency and power-factor. At the same time the motors furnishing such current will have increased heating, reduced efficiency etc., because they serve the double purpose of motor and of phase converter. In practice this means that it is necessary to increase the size of the larger motors and the high speed motors, while the size of the smaller motors and low-speed motors may be reduced. The resultant gain over straight single-phase operation is usually of no great importance. If there are few large, high-speed motors and many small, low-speed motors, the total first cost of motors may be appreciably smaller than with straight single-phase running and the overall efficiency may be slightly improved. Under no conditions will the first cost, efficiency or power-factor of the motors, compare favorably with pure polyphase operation. As a rule the use of the system is therefore not justified unless it is very expensive and inconvenient to obtain polyphase power otherwise, as may be the case in connection with single-phase railways and possibly under a few other special local conditions. For this reason the system has not been used on a large scale except in connection with electric railroads where one machine running light is used for phase converting purposes only, to supply polyphase current for a number of motors. Such systems as are actually operating are described in JOURNAL articles on "Single-phase Loads from Polyphase Systems" by B. G. Lamme, June 1915, p. 261; "The Field of Application of Phase Converter Locomotives," by R. E. Hellmund, October 1915, p. 462, and "The Split-Phase Locomotive of the Pennsylvania Railroad by G. M. Eaton and A. J. Hall, October 1917, p. 406. Theoretical papers on the subject are found in the April 1918 *Proceedings A. I. E. E.* by R. E. Hellmund and in the June 1918 *Proceedings A. I E. E.,* by C. Fortescue. These papers show clearly that the question of the polyphase voltage determination is a rather complex problem and cannot be answered briefly. Unless special balancing arrangements are used the polyphase voltages are unbalanced, with at least one of the voltages from the third terminal to the line being appreciably smaller than the line voltage. R.E.H.

1697—MONOCYCLIC SYSTEM — With the monocyclic system of generating and distribution (see Penders Handbook p. 368) what is the angle of phase of currents going out the mains, the capacity of transformers and the angle of phase difference of currents from



FIGS. 1697(a), (b) AND (c)

the secondaries of these transformers when a three-phase motor is operated from this system. Please explain by means of vector diagrams. E.M. (N.Y.)

The monocyclic system of generation was essentially single-phase in so far as the greater percentage of the load was concerned. In order to obtain a polyphase circuit for use where such power is desirable, a teaser winding was added to the armature. In some cases this winding was of such a value as to give a balanced three-phase voltage so that in such cases the angle of the phase of the current would be 120 degrees between phases corresponding to the normal three-phase system; the phase current would, of course, be affected where there was a combination of single-phase and polyphase loads. This is indicated in the vector diagram given in Fig. (c). F.C.H.

1698—CURRENT MEASUREMENT — Please explain (with diagram) how may the current of the individual phases of a three-phase, delta-connected system be measured by the use of only two current transformers. J.I.D. (CALIF.)

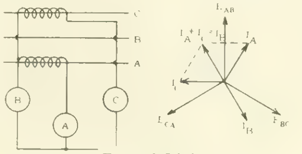


FIG. 1698(a)

One of the characteristics of the three-phase circuit is that the sum of all the currents must equal zero. Consequently, if connected as shown in Fig. (a), ammeter *A* will measure the current in line A, ammeter C will measure the current in line *C* and ammeter *B* will measure the sum of currents *A* and *C* which is equal to the current in line *B*. R.T.P.

1699—PARALLEL OPERATION—Will you please state the method of phasing out two alternating-current generators for parallel operation, giving methods suitable for small plants with limited equipment. G.T.K. (Alberta)

The conditions necessary for paralleling two alternating-current machines are approximately equal and opposite voltages of the same frequency. That is, the voltages are opposite in the local circuit made up of the two generators. They are of course in the same direction and phase in relation to the external load circuit. The machine should be brought as near as possible to the correct speed and the voltage of the incoming machine made slightly higher than that of the loaded machine, or bus-bars. To ascertain whether or not the voltages of the machines are opposite, connect lamps between the incoming machine and the bus-bars, as shown in Fig. (a), in two of the phases, *B* and *C*. Enough lamps should be placed in series across each of the switches to withstand twice the normal voltages of the machines. Thus, if the normal voltage is 110 volts, the lamps must be able to withstand 220 volts. Close the switch across which there are no lamps or *A*, and if both lamps are light or dark at the same time, the machines are connected correctly; if not, two of the leads of the machine must be interchanged. After the machines are once phased out in this manner, they will always be connected correctly if the field or the direction of rotation of a machine is not reversed. To indicate synchronism after the machines have been properly phased out, only one set of lights in one of the phases is required. The speed of the prime mover is adjusted until the beat of the lights is very slow. When the lights

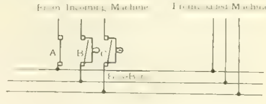


FIG. 1699(a)

are at the middle of the period of darkness, the switches *B* and *C* are closed, and the machines are in parallel. To make the machine take more load, try to speed up the prime mover. If the machine is single-phase, it is not necessary to phase out. Adjust the voltage to about the right value, with phase lights in one line and close the other line through the switch. When the lights are at the middle of the period of darkness, close the second switch and the machine is parallel. C.R.C.

1700—FAN MOTORS—I have a number of 220 volt direct-current on the re- which it is desired to work on 110 volts alternating-current on the repulsion motor principle; what sort of change is it necessary to make to the field coils after the commutator has been short-circuited? A.U. (MEXICO)

A series motor originally designed for direct-current service cannot be run satisfactorily as an induction repulsion motor unless it has a field similar to those used on standard squirrel-cage motors. The ordinary series fan motor has two poles and its field iron does not provide any path for the cross flux necessary in a single-phase motor. Moreover, it must be remembered that the synchronous speed which depends upon the number of poles would be 3600 r.p.m. for 60 cycles. It should also be noted that many direct-current fan motors are made with cast-iron poles, and are therefore not suitable for use on alternating-current circuits. O.F.R.

1701—PARALLEL OPERATION OF SYNCHRONOUS MOTOR SETS—Three synchronous motor-generator sets are in parallel. The motors are three-phase, 25 cycle, 2300 volts, with capacities of 1200 kw, 1200 kw, and 3250 kw. The generators are 60 cycle, two of them are two-phase 2400 volts, 1400 k.v.a. at 75 per cent P-F; the third is three-phase, 12000 volts 3650 k.v.a. at 55 percent P-F. A Scott connected transformer bank of 3000 k.v.a. capacity interconnects *1* and *2* with *3* for parallel operation. The excitation of the sets is as follows; — the generators of all these units are under the influence of a Tirril regulator The field of No. 3 motor is under the influence of the regulator, while the other two motors are not. A 4/0 three-conductor 11500 volt, 25 cycle lead covered, underground cable developed trouble causing a disturbance to the 25 cycle system. The cable cleared by selective relay action in 1.5 seconds. The 25 cycle system voltage, however, was kept down to 70 percent normal until the motor-generator sets above mentioned were manually disconnected from the system, which was approximately twenty seconds. It is as-

sumed that there was a phase displacement either in the generator or motors. Is it possible to have such an angular displacement so that the motors will draw between 200 and 300 percent load curent without falling out of step with the system? Does the difference in the excitation of the motors give grounds for such an occurrence. The units are located in a substation 15 miles from source of supply—a hydroelectric plant of 80 000 kw. capacity. The transmission voltage is 60,000 volts.

G.W.G. (PA.)

It is probable that the short-circuit which occurred on the 25-cycle system caused a considerable lowering of the voltage, due to excessive line drop, and this decreased voltage allowed the synchronous motors to fall out of step with the line. By the time the short-circuit was removed, the motors were running at somewhat less than synchronous speed, and although the voltage rose to 70 percent of its normal value, it was not sufficient to cause them to pull into step, since they were still carrying their original load. Under this condition, with the motors operating as induction motors, they drew an excessive current, which in turn was the reason that the voltage was not restored to normal until the motor switches were opened. It is improbable that any one of the machines got out of step with the others, since any tendency to do so would be immediately counteracted by a flow of current between the machine in parallel. The fact that both the motors and the generators were paralleled makes this more certain.

Q.G.

1702—Scott Transformation With Autotransformers — We wish to transform 75 kw from 2-phase 2300 volts to 3-phase 2300 volts. I understand that this can be done by the straight Scott transformation method. Would it not be possible, however, to combine the autotransformation principle in conjunction with the Scott transformation? If this latter can be done, it would appear that considerable saving in first cost of transformers should be brought about. Will you kindly give a sketch of how this connection should be made, and indicate approximately the saving, if any, in iron and copper by using the autotransformation principle?

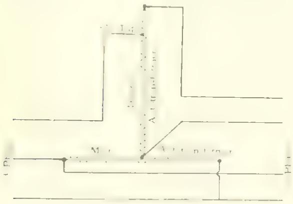


Fig. 1702(a)

L.H.R (PA.)

Autotransformers are frequently employed for stepping from two-phase to three-phase or vice versa. The connections for this transformation are shown diagrammatically in Fig. (a). In the case of a 1 to 1 voltage ratio the "main" autotransformer is built in parts corresponding to slightly less than 15 percent of the total power handled and the "teazer" autotransformer in parts slightly less than seven percent. Autotransformers may also be used to step from two-phase to three-phase with a difference in voltage. In this case the size of the transformers will depend on the voltage ratio, as discussed in the article by Mr. E. G. Reed on "Autotransformers" in the Journal for March 1916, p. 150.

J.B.G.

1703 — re 1475 (July, '17) — In question No. 1475, on the Tirrill regulator, the series transformers are cross connected. Why is it that these transformers are not short-circuited through themselves? With the connections shown an ammeter connected in one of the leads would show 1.73 times current of one transformer.

E.G.M. (N.Y.)

(a) In a series transformer the primary and secondary ampere-turns balance each other i. e. for every primary current there is always a proportional secondary current and this current must flow through any circuit available. If no circuit is available (open secondary) the transformer generates a dangerously high voltage in its effort to force a curent. If several series transformers are interconnected the current from one transformer cannot force its way through the secondary of another transformer for this would destroy the equality in primary and secondary ampere-turns. The impedance of a series transformer secondary is so high as to amount to an open circuit for any current other than its own secondary current. Hence one transformer cannot feed back through or short-circuit another unless they are in phase. (b) The current in the resultant curcuit of the series transformers is 1.73 times the current in one transformer.

C.A.B.

1704—Exciter Windings—A 125 volt, 283.3 ampere steam turbine exciter, has four poles with commutating pole fields. The armature has 57 slots. The throw of the coils in the slots is 1-15 and the leads on the commutator are 1-29. The coils come unsoldered on the commutator connections quite often and break off which means take the machine apart for repairs. Is there some way a jumper can be put around these coils to cut them out, but not spoil the coils so they can be repaired again?

L.M.D. (WASH.)

The breaking of leads to the commutator may be due either to excessive heating, caused by faulty joints or to continual vibration, even of the slightest amount. Vibration may be the result of not applying bands tightly, or of insulation shrinkage, which allows the coils to become loose. Trouble of this sort in some cases has been traced to a slight movement of the commutator spider or armature spider on the shaft. A common cause of leads coming loose where they connect to the commutator necks is improper soldering. In making such connections, the coils leads and commutator necks should first be tinned; then after wedging the coils ends in position with wooden wedges, the joints can be soldered, using half-and-half solder, and a mixture of alcohol and resin for flux. In cutting out an injured coils with a jumper, a piece of copper wedged between the two adjacent commutator necks may be used. These two necks must be a pair, having the injured coil as one of the two coils in series between them. Cutting out a coil in this way is not particularly desirable on account of the additional heating and poor commutation that results.

F.L.M.

1705—Testing Transformer For Direct-Current Armatures: — Please give me complete information with regard to size of wire, size of iron core, etc., of an armature testing transformer to work on 440 volts, 25 cycles, three-phase. It must be strong enough to test direct-current armatures from 0.5 to 150 horse-power. I would like to make it strong enough to make a "short" or a "ground" show up at once.

A.A.K. (ILL.)

The size of iron core and size of wire to be used for short-circuit testing device will depend on the size of armature to be tested, the frequency of supply and the k.v.a. that can be supplied to the device. To make it strong enough to show up short-circuits at once it must be designed for as high voltage per turn as possible. This means that the total flux passing through the armature coil must be the maximum possible. The built up length of iron in the test

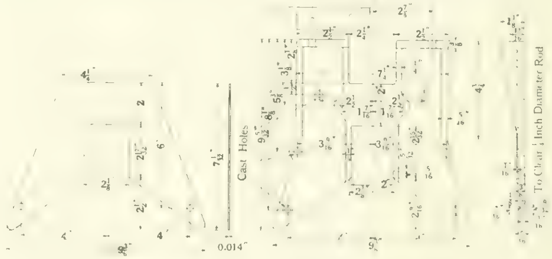


Fig. 1705(a)

device should be as long as the built up iron in the armature, and the number of turns made as small as possible. However, the smaller the number of turns, the greater the current drawn from the line will be. The flux in the iron circuit of both testing device and armature can be made 90 000 to 100 000 lines per sq. in. (maximum) in the narrowest portions. The ampere-turns per inch length of magnetic circuit in the usual laminated iron circuit should not exceed sixty (60) at this flux density. The ampere-turns taken by the air-gap between the testing device and the armature can be estimated from the formula.

$$\textit{Ampere turns} = \frac{G\ B}{4.5}$$

Where G = length of airgap in inches

and B = flux density in lines per sq. in. (maximum).

With the above data and the usual transformer formulae which can be obtained from text books, there should be no difficulty in working up a suitable design. If the iron circuit of the testing device is made to conform closely to the armature, the air-gap can be made small, but if it is made to fit a large range of sizes the area of contact will be small for some sizes and the effective air-gap of considerable value. Probably taps on the winding would be desirable to give some control over the current drawn from the line for different armatures. The size of copper used should be about 1000 circ. mils per ampere. This will depend somewhat upon the radiation constants of the design and the length of time it is to be kept in service. If the service is less than one-half the elapsed time in intervals of not over one-half hour the size of wire can probably be reduced. While it is contrary to the usual JOURNAL policy to furnish specific designs, a typical design will be given in this case for an example. The shape of punching for a testing device suitable for armatures from 3.5 in. minimum diameters, up to 12 in. maximum diameters, is shown in Fig. (a). The punchings are built up to a height of 5.5 in. giving a total weight of iron in the magnetic circuit of approximately 37 pounds. Plates of heavier material will be needed on each end to hold the laminations together, a satisfactory form of end plate being also shown in Fig. (a). The windings for 440 volts, 25 cycles would consist of 576 turns of number 14 double cotton covered wire, representing a net weight of approximately 13 pounds. The exciting k.v.a. with such a transformer without an armature in the air-gap will be of the order of 4.5 k.v.a. The exciting k.v.a. with an armature in place will depend to a large extent upon the area of contact and will be of the order of 1.5 k.v.a.

W.R.W.

1706—PARALLEL OPERATION OF ALTERNATOR:—Two alternators, one of 150 kw capacity and the other of 225 kw capacity are run in parallel. Their exciters are not paralleled and the larger one is controlled by a Tirrill regulator. The exciter voltage of the 150 kw machine remains at 52 volts, that of the 225 kw machine varies on account of the regulator from 52 to 135. Under these conditions what kind of service can be expected under severe overloads? The totalizing ammeter indicates 130 amperes and the small alternator ammeter indicates 40 amperes. There is no ammeter on the large alternator. Is it possible for the small generator not to take its share of the load when there is a large load on the line. The difference in exciter voltages would indicate a large cross current but the ammeter does not indicate it. When there is a difference of 25 volts between exciters on no load there is a cross current of 40 amperes. The load is 440 volt induction motors but we have only 250 to 300 volts when the heavy load is on. Will this load have a lower power-factor than motors with suitable voltage? Which alternator if either (the under-excited or over excited) will take the wattless load? Is it true that the small alternator will take a power load even though under excited, due to the fact that the prime motor attempts to run at a fixed speed but the alternator is held back by the 225 kw machine, it running slower on acount of heavy load.

J.H.B.

The energy load which each generator carries is not influenced by its excitation, but depends upon the setting of the prime mover governors. The machine which has its excitation increased takes the greater part of the wattless load. The full-load voltage could be improved by raising the exciter voltage of the small machine to considerably above 52 volts. This will mean that the small machine is over excited at no-load and there will be a current flowing between the two generators. It will not be a serious matter, as compared with the present condition at full load, provided the cross current is not too great. The increase in exciter voltage may be made such as to give the best compromise between full load and no-load operation. The power-factor of a 440 volt induction motor when operated at from 250 to 300 volts may be practically the same or even slightly higher than when operated at normal voltage. However, it is highly undesirable to operate a motor at this reduced voltage since it takes a much higher current, resulting in higher losses and increased temperature, and since its speed is decreased slightly and its ability to carry overloads is greatly reduced. For a discussion of the exact effect of operating induction motors on lower than rated voltage, see article on "Effect of Voltage or Frequency Variation on Induction Motor Characteristics", by L. W. Smith in the JOURNAL for March 1917, p. 105, also questions 1076, 1493, 1517 and 1528.

Q.G.

1707—BLASTING BATTERY — We have a three-pole blasting battery which is giving us some trouble with missed holes. It is a 50 hole battery 25 each way from the center connection. In operating, the plunger rotates the armature and when it gets near the bottom it opens the upper contact of the switch by forcing the spring down until it touches the lower contact of the switch. The distance between contacts is about one-half inch. I do not under stand how the generator is excited after the upper contact is broken. In any case would there not be considerable interval between explosions?

J.C.H. (CAN.)

When the upper contact is closed, the series generator which is then short-

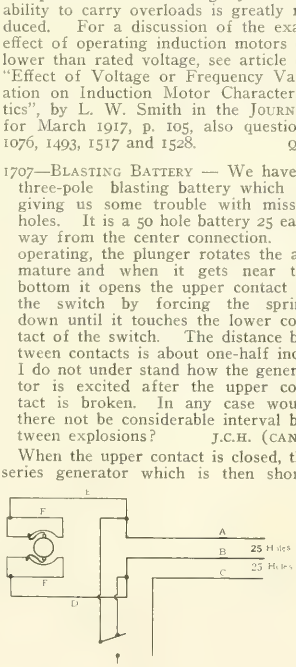


FIG. 1707(a)

circuited, builds up very rapidly. When the upper contact is opened, current is sent through the circuit EABD and 25 holes are fired. After the first 25 holes are fired and before the lower contact is closed the generator is on open circuit, but owing to the magnetic lag of the field the machine continues to run while the plunger forces the spring from the upper to the lower contact. When the lower contact is closed current is sent through the circuit ECBD, and the remaining 25 holes are fired. If the contacts are properly located the time between explosions will be very short, since the time interval is due to changing from the upper to the lower contact. The missed holes may be due to poor brush contact or improper spacing of contacts.

H.E.D.

1708 — HOIST MOTOR — We are having trouble with an electric hoist of two tons capacity. The motor is 1.75 hp, 220 volts, direct-current series wound. The hoist is used in foundry work. The trouble is that it hoists and lowers too fast. We changed the 1350 r.p.m. motor for an 850 r.p.m. motor, but this was still too fast. We have tried reducing the voltage and also putting more resistance in the circuit, but that does not reduce the speed enough. About eight feet per minute is the lowest speed we can get. What is the lowest speed at which this motor should run under load? Would a compound motor with a heavy series winding be any better?

H.D. (MICH.)

The hoist motor on this crane is probably operated by a drum type reversing switch, this switch providing no control points. If such is the case, the motor speed and therefore the hook speed would vary with the load. If the loads to be handled are fairly uniform in weight, there is no reason why the motor speed cannot be reduced by means of a permanent resistance. Sufficient resistance can be put in series with the motor to give the desired hoisting speed. It must be understood, however, that with the resistance permanently in series with the motor, the speed will vary when lifting loads of different weights. As the crane is used for foundry work, we believe what is desired is some form of speed control. This could be obtained by having a controller with two or more speed points for both hoisting and lowering. The variation in speed could be obtained by a series resistance, or by a combination of series resistance and a shunted armature connection. The latter method of control would be preferable, as it would provide a control point which would give very easy starting when hoisting the load and also speed control when lowering the load. The speed at which a series motor should run under load of course depends on what the load is and the speed for a given load cannot be reduced except by lowering the voltage or using series resistance. It does not seem that a compound wound motor would be necessary for this service.

R.R.S.

1709 — TURNING MINE LOCOMOTIVE WHEELS—In a coal mine where direct curent is used for hauling purposes with mine locomotives where one and two tracks of 40 or 60 lb. steel is used, where the track acts as return conductor for the current, where the current varies from zero to 200 amperes, where track is all bonded, what effect if any has this current on the rail and on the steel locomotive truck wheels. The design of our truck wheels is such that after the tread wears down and the flange gets too high we turn them down and get

another period of service out of them. We find the wheels so hard that we must first anneal them before we can turn them. The steel rail is so hard that it is impossible to cut it with any degree of success. After annealing the wheels they are too soft and their life is very much decreased. Is there any grinding device on the market to dress down these wheels without the annealing process? E.C. (W.VA.)

Current passing through the wheels and rails of a locomotive does not affect the hardness or softness of the steel. Where locomotive wheels slip frequently on sanded rails, the face of the wheel becomes hardened in spots. Also sparking caused from the current flowing from the wheel face to the rail when sand is used excesively, causes hard spots on the face of the wheel. These two actions cause a hard surface over the face of the wheel and it is very difficult to find a tool that will cut it successfully. Steel tired wheels, however, or rolled steel wheels are successfully turned by use of a high-grade tool steel. We feel sure that a little experimenting, and the advice of tool steel manufacturers will determine the proper kind of steel for the most severe conditions. There are grinding devices for smoothing out flat spots in wheels, but to attempt to cut down a grooved wheel with a grinding machine sufficient amount to make it run true has been found impracticable, due to the undue amount of time necessary and consequently the expense to complete the work. The machine tool manufacturers have grinding lathes for this kind of operation. A.P.S.

1710 — Noise in Induction Motor — What is the cause of a peculiar noise in a 1000 hp, three-phase, four pole, 60 cycle induction motor? The motor drives a centrifugal pump and vibates under load depending on its slip. Under light load or no load the noise disappears. As far as I can judge the shaft is amply large and the motor does not rub the stator. The number of stator slots is 60 with six bars per slot. The wound type rotor has 82 slots with one bar each. What would eliminate the trouble? I think the rotor winding is an unhappy choice. M.S. (N.Y.)

Magnetic noises in general are caused either by the main rotating field or by the leakage flux. In the first case the noise is present at no load and at all other loads in about the same amount, but in the second case there is little noise evident at no-load but the noise increases with the load. The particular reason in this case seems to be as you suggest, due to the fact that 82 rotor slots is not a good combination with 60 stator slots for a four-pole winding. The condition could probably be improved by changing the stator winding so that all four poles would be in parallel or two series of two parallels each with equipotential connections at the middle of the phase and connecting the two parallels. If the latter connection is adopted the winding should be arranged with two adjacent poles in series so that the equipotential connec-

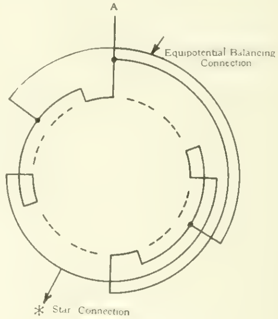


Fig. 1710(a)

tion will be diametrically across the winding mechanically as indicated for one phase only in Fig. (a). See also article on "Design of Machines for Quiet Operation" by G. Pontecorvo in the Journal for September 1913, p. 860. A.M.D.

Engineering Notes

Aim—To connect theory and practice

Reversing the Direction of Rotation of Single-Phase Motors

Single-phase motors in general are divided into four classes, namely split phase, repulsion starting, shading coil and series motors.

Split-Phase Motors have two distinct windings, a main running winding and a high resistance starting winding which are connected to the circuit as shown in Fig. 1. The direction of rotation of the motor is reversed by interchanging the terminals of either one of these windings, but not both; *i.e.* *C* and *D* may be interchanged or *A* and *B* may be interchanged. The reason for the reversal is the same as in a two-phase motor, one of the phases is reversed by interchanging the leads.

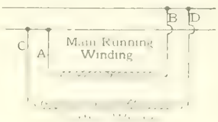
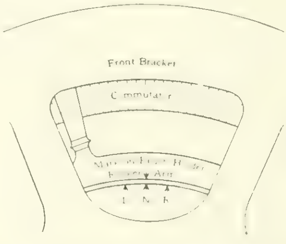


FIG. 1—SCHEMATIC DIAGRAM OF SPLIT-PHASE MOTOR WINDINGS

Repulsion Starting Motors have an armature winding, a commutator and brushholder similar to direct-current machines, the brushholder being short-circuited through the rocker arm. Reversal of the direction of rotation of these motors is accomplished by shifting this rocker arm relative to the supporting bracket, as shown in Fig 2. An arrow is stamped on the movable brushholder, which may be put opposite any one of the three marks on the stationary bracket. The middle one of these marks is known as the neutral and, when the brushholder is in this position, the motor will not start in either direction. When the brushholder is shifted to one side or the other of this neutral, as indicated by the marks *R* and *L*, in Fig. 2, the motor will run right hand or left hand respectively.

Shading Coil Motors have only a single winding connected to the line, and it is obvious that reversal of the terminals of this one winding will not reverse the direction of rotation, since the motor operates on alternating current. The obvious method of reversing the direction of rotation of such motors is to shift the short-circuited starting coils to the other side of each of the main poles. This, however, is quite difficult to accomplish and it is usually much easier to reverse the motor by



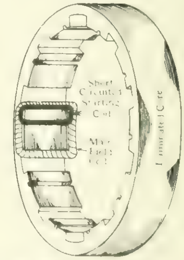


FIG. 2—ROCKER ARM OF REPULSION STARTING MOTOR

FIG. 3—MAGNETIC CIRCUIT OF SHADING COIL MOTOR

taking off both end brackets and turning the complete stator end for end relative to the rotor; or else by taking out the laminated core with the windings in it, and reversing it end for end relative to the rotor.

Series Motors of the commutator type are reversed by reversing the direction of current through either the armature or the field, just as in a series direct-current motor.

A. M. Dudley.

THE ELECTRIC JOURNAL

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Three-Phase to Two-Phase Transformation

The problem of transforming from three-phase to two-phase has probably been productive of more solutions (either accurate or approximate) than almost any other problem in electrical engineering. The commercial features which originally lay back of this problem, together with the history of its initial developments were described by Prof. Charles F. Scott in the January issue. While many of the commercial advantages of the two-phase distribution system have now disappeared, by reason of the fact that practically every distribution system now covers such an extensive area as to be in effect a transmission system, there are many two-phase installations in operation and methods of transformation are still useful.

The three-phase to two-phase transformation has suffered an unenviable reputation in some quarters for giving poor voltage regulation and distorted phase relations, principally on account of the lack of a complete understanding of its characteristics. That this reputation is merited, where suitable magnetic relations between the two halves of the main transformer are not maintained, is beyond question, but where the two halves of this winding are suitably interconnected, as is practically always the case in modern distribution transformers designed for three-wire operation, the regulation is almost as good as with any other form of transformation, and the phase distortion is negligible.

Occasions for transforming from two-phase to three-phase are frequently the result of emergency conditions, so that especially designed transformers are not available. Hence many approximate schemes have been developed for using standard distributing transformers for this purpose. These schemes are quite satisfactory under emergency conditions, but most of them would hardly be employed if transformers are to be purchased for the purpose. For a permanent installation, the Scott connection still remains the best.

The two-phase three-phase connection was originally devised for use with motors which were deliberately built for a different number of phases from the transmission system over which they were to receive power. While this is not common practice at present, circumstances sometimes arise which make such a plan advisable. A recent instance is that of the Norfolk and Western locomotives in which power from a single-phase trolley is fed through a two-phase rotating phase converter to three-phase induction motors. Another warrantable occasion is where a large rotary converter is to be fed from a two-phase system. Since transformers are necessary in either case, the superiority of the six-phase over the two-phase converter will frequently warrant a two-phase to six-phase connection.

Because of the simplicity of the Scott connection, especially when autotransformers are employed for voltage ratios near unity, the rewinding of induction motors to change them from two-phase to three-phase or vice versa is frequently questionable. Undoubtedly such rewinding is justifiable in many cases; but in every case the alternative of using Scott-connected transformers or autotransformers should be carefully considered from the standpoint of cost, time and overall operating performance, as the k.v.a. rating of the autotransformers need be only a small percentage of that of the motor. The articles in this issue by Messrs. E. G. Reed and J. B. Gibbs, in connection with the one by Prof. Scott in the January issue, form a quite complete resume of this important subject.

The Journal— A Text Book

The Electric Journal has recently been adopted in a prominent engineering school as a text for the study of English. This is certainly a step in the right direction. While modesty forbids recommending our own magazine, the study of technical articles by engineering students of language must prove more useful than the study of Chaucer or Shelley under an instructor who is unfamiliar with engineering terms. The objection to the intensive study of English in technical schools has always been lack of time. But it is impossible to turn a high school graduate into an engineer in four years in any case. The most that can be attempted is to lay a good foundation for future development—of which the concise and accurate use of language is almost the corner stone.

There would seem to be no good reason why the study of English should not, to a large extent, be made an integral part of the other courses. Corrections in the wording of laboratory reports have always been made to some extent. It is difficult, however, for any individual to examine a paper from two radically different view points—and all too often the laboratory instructor is not qualified to make suitable corrections and suggestions. If these reports are graded and corrected by the Department of English from the standpoint of language only, in addition to the usual grading from the standpoint of engineering by the laboratory instructor, they should give the student ample practice in writing, without adding materially to his total work.

Moulded Insulation

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THIS ARTICLE is written particularly for the engineer who has occasion to use moulded insulation in his designs. In many instances he has never visited an insulation moulding plant to familiarize himself with how such work is carried on. Realizing the difficulty of successfully designing moulded insulation blocks without a knowledge of such work, an effort is made in the following article to give information on this subject that will be helpful. It is recommended that everyone responsible for the designing of moulded insulation visit a plant doing this work whenever an opportunity is offered. There are so many things, apparently of a trivial nature, that are of great importance to the moulder, that the better the designer understands the art of insulation moulding the more successfully can his designs be manufactured.

PROPERLY handled, moulded insulation will often prove to be a friend in need. Improperly applied it may lead to much trouble. The designing engineer should acquire the same knowledge of this material before applying it and give it the same careful consideration that he gives to die castings, for instance, or bearing metal. Too often he carefully works out every other feature of his design and then assigns any space that may be left to the moulded insulation. Later he wonders why the moulded piece costs so much or why it fails on trial.

Moulded insultations may be classified in three different ways; first, with respect to the method of moulding; second, with respect to its action under heat; and third, with respect to its action in a flame. Under the first classification the product may be further divided into "hot moulded" and "cold moulded" materials.

Hot moulded materials are those formed by subjecting the moulding mixture to heat and pressure simultaneously in a mould. The binder may be any adhesive material that becomes active when heated, such as shellac. The filler may be any suitable material, such as asbestos.

Cold moulded materials are those which are subjected to pressure in a mould without the application of heat at the same time. The piece is removed from the mould and afterward subjected to the necessary treatment to set the binder. The binder may be any material which has sufficient binding power when cold to allow the removal of the moulded block from the mould, such as Portland cement or pitch in solution. The filler may be any suitable material such as asbestos.

Under the second classification, "Action under Heat", moulded insulation may be divided into softening and non-softening materials. The softening materials are those which become soft and flow when subjected to heat and pressure after being moulded. Such materials are the shellac mixtures, hard rubber, moulded pitch products, etc. The non-softening products are those which do not soften under heat and pressure such as the phenolic condensation products, cement-asbestos mixtures, silicate of soda mixtures, etc.

The third classification, "Action under Flame", refers to the action of the materials when subjected to the impact of a flame. Under such treatment moulded insulation divide themselves into combustible and non-combustible materials. The combustible materials are those that will burn or carbonize, such as shellac mixtures, hard rubber and condensation products.

The non-combustible materials are those that do not carbonize in a flame, such as asbestos-cement and silicate of soda mixtures.

Hot Moulded Materials—In the manufacture of hot moulded materials three classes of binder are in general use. First gums, such as shellac and copal, which become soft and plastic when heated and hard when cold. These gums are mixed with short asbestos fibre, cotton fibre, ground mica, infusorial earth, barytes or any of a great variety of materials. A proper combination of gums and fillers is selected to produce the particular result desired. These materials are then mixed for moulding by grinding together, by mixing on hot rolls or by means of a solvent which is afterwards driven off. The material is then either placed in the mould and the mould is placed in a press that is first heated to fuse the binder, then cooled to harden it; or both the mould and material are heated, the material placed in the mould and the mould placed in a cold press where the piece forms before cooling and hardening.

The second class consists of what is known as phenolic condensation products. They are synthetic resins which have the property of hardening throughout on being subjected to continued heating. Using, for the purpose of illustration, the most commonly known materials, these products may be formed by mixing together, under proper conditions, carbolic acid and formaldehyde in the presence of ammonia. Quite a variety of materials of similar chemical nature may be substitued for those mentioned. Three makes of these products are now on the market. They are known as Bakelite, Condensite and Redmanol. The moulding mixtures are made by mixing the resin with wood flour or asbestos fibre. The former mixture is prepared both in powder and in sheet form. The latter is made only in powder form. Also the varnish—(resin in solution)—is spread on paper or fabric to produce what is known to the trade as "micarta".

These materials are always moulded in a hot press as they require the application of heat for a definite length of time to harden the binder.

The third class of hot moulded insulation is hard rubber or vulcanite. This consists of crude rubber mixed with filler and a vulcanizing agent, generally sulphur. Hard rubber moulding is carried on in much the same manner as the condensation resin moulding, except that the stock is always prepared and handled in sheet form.

Characteristics of Hot Moulded Materials—Each of the above three classes of materials has distinctive characteristics which should govern its selection for any given case. The first which is commonly known as "shellac" mixture or "rubber substitute" has the property of softening and distorting if subjected to pressure and heat at from 40 to 60 degrees C. It is also comparatively weak mechanically, but has good dielectric strength and in simple shapes is the cheapest of all hot moulded insulations.

The phenolic condensation products are characterized by their high mechanical strength and by the fact that, when fully cured, they do not distort at any temperature up to 150 degrees C. When properly used, this class of materials can be made of great value to the designer of electrical apparatus. In using any of the moulded insulations, however, he must allow the same factor of safety that he uses for other parts of his apparatus.

Hard rubber is characterized by its high insulation values. It also has quite good mechanical strength though not so good as the phenolic condensation products. Hard rubber will distort under load at from 60 to 80 degrees C. temperature. These comments refer to high-grade hard rubber. It may be loaded with adulterants to cheapen the product until it is little better than the shellac mixtures.

Cold Moulded Materials—In the making of cold moulded insulation, two general classes of binder are used. First are those that can be dissolved to facilitate mixing with the filler, the solvent being driven off by heat after the pieces are moulded. Second, those that set by chemical action.

In the first class the most common binder is pitch. The pitch is dissolved in benzine or naphtha and mixed with the filler, usually asbestos fibre. The product is moulded while the mixture is still plastic, due to the presence of the solvent, and the pieces are then dried in an oven until all solvent is driven off. The result is a hard product with more or less strength depending on the ingredients used and the skill exercised in the manufacture.

A second binder used is phenolic condensation resin in solution with alcohol or benzol. After forming the block the solvent is driven off and the heating continued until the resin is "polymerized" or permanently hardened. In this case absestos fibre is again the most commonly used filler.

A third binder of this class is silicate of soda dissolved in water. It is worked in the same manner as the others, namely mixed with the filler while in solution and then dried in an oven.

The second class of cold moulded insulation, in which the binder sets by chemical action, may be represented by:—First—Portland cement with asbestos fibre in which the cement sets by combination with water and afterward has the excess water driven off by heating. Second—Lime and silica mixed with water and a filler of asbestos, magnesia, etc. In this case the lime and silica combine to act as a binder when properly treated. The product is afterward dried.

Characteristics of Cold Moulded Materials—The prominent characteristics of the cold moulded insulations mentioned above are as follows:—

The pitch mixtures, when thoroughly baked, will soften at from 60 degrees C. up. These materials are fairly strong and will resist blows better than porcelain. They are cheap, as compared to the hot moulded products, and are quite satisfactory where too much in the way of electrical and mechanical strength is not required of them.

The cold moulded phenolic condensation products are stronger mechanically than the pitch products and will not soften or distort below 150 degrees C. They are not nearly so strong mechanically or electrically as the same products hot moulded.

The silicate of soda product is generally quite weak mechanically and electrically but will stand much more heat than the materials with organc binder. It resists the action of flame quite well but tends to take up moisture from the atmosphere. It is, therefore, not reliable for insulation unless located in a position where it is continuously heated, or well protected from air.

The Portland cement product is stonger than the silicate of soda mixture and is not weakened by moisture. It is, however, not so strong as the hot moulded products. It will stand much more heat than the organic mixtures, the limit being the temperature at which the cement is dehydrated, after which it becomes brittle. This material may be used safely up to 400 degrees C. It is porous in structure and can be waterproofed to preserve its insulation value unless used at temperatures that would burn out the waterproofing ingredient.

The lime-silica product is not so strong as the Portland cement mixture but will stand more heat without losing its strength. It is, therefore, better adapted to high temperature work.

Summarizing, the hot moulded insulations possess higher insulation values, greater mechanical strength and take better finish than those that are cold moulded. The cold moulded materials are cheaper when produced in quantity, except when the pieces are small, and for the most part will stand more heat.

No attempt will be made to give definite values of the electrical or mechanical properties owing to the great variation due to differences in ingrediments and skill exercised in manufacturing the products. As an illustration, the most common filler used in the phenolic condensation moulding mixtures is wood fiber or wood "flour". Wood has a strong affinity for moistuse and will absorb it from the air if exposed after being thoroughly dried. Left to its own devices, wood will take up about ten percent of its weight in water from the air. Inasmuch as one percent of moisture will render an insulation very poor, it is evident that moulding mixtures containing wood flour as a filler must be handled with great care. Of course, the binder will coat the fibres and protect them to a considerable extent but until the mixture has been moulded into a dense nonporous body the fibres are not wholly protected and exposure of such mixtures to the air for even a few hours is apt to cause rapid deterioration. For this reason the insulation value of all phenolic condensation products using wood flour is dependent on the care in handling. The same thing is true to a lesser extent with those mixtures using asbestos as a filler.

APPLICATIONS OF MOULDED INSULATION

The designing engineer cannot get best results from the use of moulded insulation without at least a general knowledge of how it is formed. The moulding operations are briefly as follows:—

As indicated by its name, moulded insulation is formed in a mould from stock that is more or less plastic. The material may be plastic when cold as in cold moulding, or the material and mould may be heated before or during the application of pressure. Pressures of from one-half to five or six tons per square inch are used to form the block, depending on the material, size and shape of the product. With such pressures it is necessary to make the moulds of very hard metal in order to get a reasonable production before the mould wears out. Such moulds are expensive and their cost often limits the use of these materials.

Before deciding on the use of moulded insulation the designer should assure himself either that a moulded piece is necessary or that the activity will justify the expense of a mould. It is often cheaper, in case of small production, to machine the required block from solid stock or build it up from disks, bushings, etc., that can be cut from plates or tubing. Even for an active piece it may be more economical to make it in this way. All such possibilities should be carefully considered.

There are sometimes reasons for using moulded insulation instead of built up parts, other than mere economy. A good finish and uniform color is always assured with good grades of moulded insulation. Again, it may be worth the mould charge to be assured of the performance of the material in service, as a preparation for expected large activity.

Moulded insulation can often be used in place of metal parts to advantage. For instance, where weight is a prime consideration as in airplane parts, the weight may be considerably reduced in this way. The weight of moulded insulation is from one-fifth to one-fourth that of steel on equal volumes, depending on the ingredients of the moulding mixture. A hot moulding mixture with wood flour filler weighs half as much as aluminum on the same basis. Moulded material is often used in place of metal on account of its better, cheaper and more permanent finish, such as radiator caps for automobiles.

Many parts that must be quite accurate as to dimension can be made more cheaply from moulded insulation than metal as the moulded block comes to the size of the mould and the pieces are always alike, except in the direction in which the pressure is applied. This latter dimension may vary somewhat.

SELECTION OF MOULDED INSULATION

A certain designing engineer, holding quite a responsible position, calls all moulded insulation "junkite". He says it is all bad and to be used only when nothing else can be found and different trade names mean nothing to him. With his present information his stand is right because he has been unwilling to give the subject sufficient study to apply the material intelligently. If he had treated other materials, such as marble, slate, mica, etc., to as scant an investigation as he has moulded insulation, he never could have been a successful designer of electrical apparatus.

In selecting the proper moulded insulation for any specific application the designer should make a careful study of all conditions to which it will be subjected. The most important points that should be investigated are:—

1—Heat conditions—What is the maximum temperature?
What is the average temperature?
Is the heat applied steadily or intermittently?
2—Electrical Conditions—What is the voltage?
What kind of current?
Is it high or low frequency?
3—Mechanical Conditions—What load is applied?
Is load steady or intermittent?
Is it vibratory?
Is it an impact?
4—Exposure Conditions—Will the insulation be exposed to rain, steam, oil, dust, smoke?
Will it be used in the salt air of the sea coast?

After outlining the working conditions which affect the insulation, it may or may not be easy to select the proper moulded composition. If the device is exposed to severe weather conditions the insulation must not be absorbent. If it is exposed to both smoke and moisture and the design is such that a coat of moist soot will be formed across the surface of the insulation, then a composition with a minimum of organic matter should be used so that leakage current over the surface will not carbonize the insulator and cause

a short-circuit. If the apparatus will be subjected to a material temperature rise above normal air temperature, then a composition should be selected that will not soften under such increased temperature. If the mechanical load is heavy or vibratory use a composition of high strength. For an impact load use a very fibrous composition.

Moulded insulations have been developed to meet most such conditions and are available to the designer who is willing to make a search for them and study of them. The great utility of moulded insulation in electrical apparatus has caused much development work to be done in this field in recent years.

The success of the use of moulded insulation depends on selecting one that will meet all the above conditions. In making the proper selection, after all these conditions have been considered the usual tendency is to allow too small a margin of safety. The best course is to "play safe" and allow a good working margin between the working conditions and the properties of the moulded material selected.

No single material has yet been devised that possesses all the desirable properties and no objectionable features, in spite of the claims made for some of them. Excessive mechanical strength is generally accomplished at the expense of electrical strength. High dielectric strength is most often accompanied with brittleness. The final choice then in many cases, where service conditions are severe, will be a compromise. The designer should use great care in studying the properties of the various moulded insulations available in effecting this compromise.

The above suggestions may appear simple and self-evident to the reader who has not been in trouble with his insulation, but the experienced man knows how easy it is to err on some very important consideration. The study of the insulation requirements should go hand in hand with all other features of the design and, before the design is complete, the exact kind of insulation should be selected and the design worked out to accommodate that material. Otherwise, the designer may be forced to use an unsuitable insulation or to change his design to accommodate the proper material. No insulating material can be made in every form, so the ability to manufacture the desired form should be determined before the design is completed.

Testing Railway Control Equipment

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THE TESTING of railway equipment is essential to insure a product free from defects. Since such equipment is subjected to a continual vibratory motion, due to the jolting of the car, and at times has to perform its functions under the most adverse weather conditions, the tests must necessarily be of a very rigid nature. The methods and apparatus used in testing control equipments will therefore be of interest to all who are in any way concerned with the operation and maintenance of railway apparatus.

THE UNIT SWITCH

To understand the operation of the switch and be able to appreciate fully why certain tests are made, it is necessary to know the construction of the switch and its principle of operation. Fig. 1 shows a cross-section of a unit switch assembled in a type *HL* control box. It is an electro-pneumatic switch, the operation of which is as follows: The magnet coil, Fig. 2, when energized from a low-voltage circuit, pulls down the steel armature *A* causing the upper valve stem *B* to close the exhaust valve *C* and to open the inlet valve *C* and to open the inlet valve *D*. The air then flows through the inlet valve into the switch cylinder *E* exerting a force on the piston *F* thereby closing the switch. As the minimum air pressure used on the unit switch equipments is 50 pounds per square inch, a good contact at the switch jaws *G* is always ensured. To open the switch the magnet coil is de-energized, allowing the small spring *H* to close the inlet port and open the exhaust port, whereupon the heavy spring *I* in the cylinder, which is compressed when the switch is

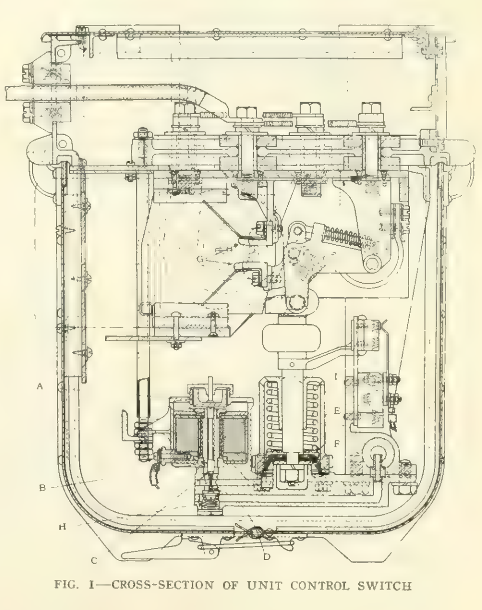


FIG. 1—CROSS-SECTION OF UNIT CONTROL SWITCH

closed, immediately assumes its original position, thereby causing a rapid opening of the switch.

GENERAL TESTING AND APPARATUS USED

When testing an equipment it is necessary to duplicate operating conditions, as nearly as possible. This means that the entire outfit, consisting of a control box, master controller, reverser, line switch and auxiliary apparatus, must be connected to a set of suitable motors. The air used during the tests must be fed through a suitable reservoir which will tend to keep the air pressure at a constant value, and through a reducing valve, by means of which any pressure desired can be obtained.

Before applying the motor current the following tests are made on the control circuits. The sequence of switches is checked by moving the controller handle around notch by notch from the first series position to the full parallel position, and the operation of the different switches is noted. Where the motors are to be cut out by means of the control circuit, the control cut-out drum is placed in its various positions, and each new sequence is checked to the schematic diagram of the motor circuits. The overload trip, Fig. 3, is wired in series with the motors, the discs of this trip being connected in series with the magnets whose

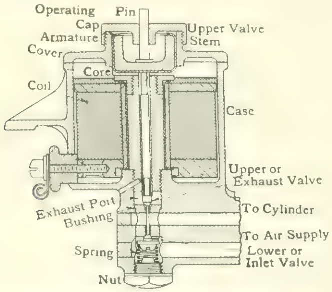
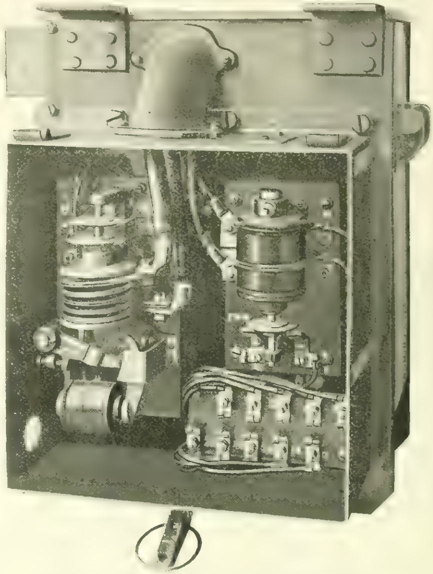


FIG. 2—CROSS-SECTION OF MAGNET VALVE

switches must be closed to complete the motor circuit. For this test the overload trip is operated by hand, and the switches acted upon are noted. When automatic equipments are used a limit switch, Fig. 4, is wired in the motor circuit, in addition to the overload trip. The disc of this limit switch is wired in the circuit which energizes the magnet coils. This circuit is so arranged that when a switch is closed, its coil is automatically transferred to a holding circuit that is independent of the limit disc. At the same time the limit disc circuit is automatically transferred to the magnet coil, which operates the next switch in the sequence. The function of the limit switch, or accelerating relay as it is sometimes called, is checked by a push button wired in series with the disc. By opening and closing the push button, the action of the limit switch under motor current control is duplicated. This is the method used to check the sequence of switches on an automatic equipment.

Where operating conditions require it, a compound limit switch is used. This compound limit is the same as Fig. 4, except that it has a shunt coil of fine wire wound around the core on the inside of the series turns. The shunt coil is connected to the control circuit, and is so arranged that the magnetic forces set up by it oppose those set up by the series coil, thereby raising the limit setting. A push button normally



FIGS. 3 AND 4—OVERLOAD AND LIMIT RELAYS

held open by a spring is connected in series with the shunt coil. The button is placed near the motorman so that he can raise his limit setting whenever it is necessary. The function of the compound limit is the same as the series limit, and is checked in the same manner except for an additional check to determine that the magnetic forces are opposing each other. It is

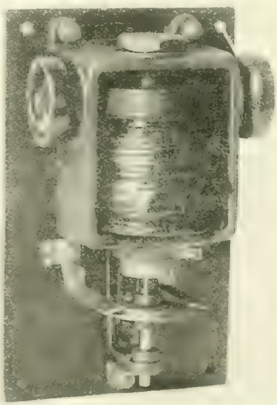


FIG. 5—LINE RELAY

evident that if these forces were assisting each other, the limit setting would be decreased rather than increased. The method of checking this function will be explained in the motor tests. A low-voltage high-cur-

rent source of power is used to calibrate all limit switches and overload trips.

A line relay, Fig. 5, connected between trolley and ground, is used on some automatic equipments. The disc of this relay is connected in series with the line switch magnet coils. The function of this relay is to

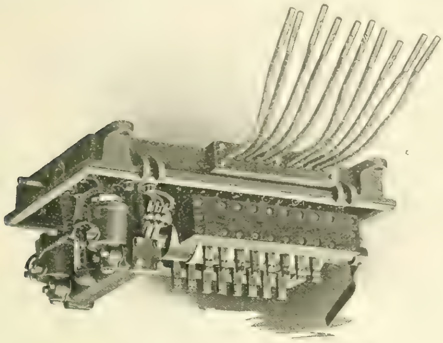


FIG. 6—REVERSER WITH COVERS REMOVED

drop out all the switches when the trolley circuit is off. A knife switch wired in series with the relay disc is used to check this function. Opening and closing the knife switch represents the power going off and coming on. This is a check on the interlocking scheme, which, if not right will produce a false operation of the switches in the group.

Since the switches must perform their functions at a low voltage, the line voltage is decreased to a specified value, and the sequence of switches is checked with this low voltage. The magnets are tested for air leaks which assures a good valve seat and a correct alignment of the different valve parts. The air pressure on a car is not constant and these control equipments must necessarily operate over a large range of air pressures. The pressure is therefore reduced and the sequence of switches checked as before.

The reversing switch, Fig. 6 changes the direction of rotation of the motor by reversing the field leads of the motor with respect to the arms. This reverser is of the air operated type. It is not expected to break any motor current and is therefore not supplied with blow-out coils. To prevent the reservoir from operating when the motor current is on, an interlock, placed on the reverser drum, is wired in series with the line switch magnets. The arrangement of this interlock is such that the reverser must be fully seated in either the forward or the reverse direction before the line switches can operate. To check this function the reverser is placed in the reverse position. The steel armature is removed from the forward magnet. The master controller is then notched around, the reverser lever being in the forward position. If the equipment is correctly wired the line switches will not operate.

The equipment is now ready for the motor test. In this test it is necessary to duplicate the varying load conditions of a car. This is accomplished by the use of two railway motors provided with suitable brakes.

In the motor test, as in the control test, the master controller is first notched up slowly to check the motor wiring. The equipment is then put through a severe test, during which the master controller is handled by a tester who studies operating conditions. During this test the action of the arcs, caused by the opening of the switches is also noted. This is essential as each switch is equipped with a magnetic blow-out which should force the arc outward, but can be connected such that the magnetic forces would be acting in the wrong direction, and would therefore blow the arc inward. Having operated in the forward and reverse positions, the motor cut-outs are moved to cut-out positions and the different combinations checked for single motor operation.

The final motor test is to check the compound limit. The progression of the switches is governed, through the control circuits, by the action of this compound limit as it lifts and drops under the influence of the motor current. The motor brakes are therefore set so that the current will vary enough to give this lifting and dropping effect. With the limit shunt coil de-energized, the master controller is now moved quickly to the full parallel position, and the value of the current at the time the limit drops is noted. The shunt coil is then energized and the previous test is repeated. If the shunt coil is connected properly, the limit disc will drop at a higher current value than when the shunt coil is de-energized.

The wires for testing are now disconnected, and the equipment is given an insulation test as follows:

From the 600 volt leads and contacts to ground 3500 volts alternating current is applied for one minute. Between 600 volt leads, with the switches

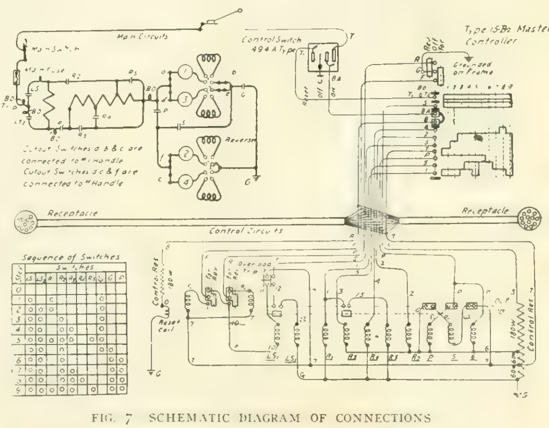


FIG. 7 SCHEMATIC DIAGRAM OF CONNECTIONS
Type HL unit switch control.

open, 3500 volts alternating current is applied for five seconds. All control wiring is tested to ground with 2500 volts alternating current for five seconds. Between such control circuit fingers and contacts as are

open in the operating positions, 500 volts is applied for five seconds.

A final inspection is then given the equipment. The tester examines all switch contacts to see that they make even contact. Interlock fingers are examined to see that they make uniform contact and have a specified pressure. The marking of all control and main wiring is checked to see that it conforms to the diagram of the apparatus.

A knowledge of the troubles liable to be encountered, and the method used in locating them, is also valuable to the repairman who has to find these troubles when the car is in service. It is not absolutely essential that the repairman should know the wiring diagram. However, it is obvious that a working knowledge of the diagram will enable the repairman to locate the trouble much quicker, thereby preventing cars from being sent to the barn as "dead cars." The control schematic diagram, a typical example of which is shown in Fig. 7, should be studied in conjunction with the main diagram. This control schematic is a simple form of diagram, showing at a glance how each magnet coil is energized. It is much smaller in size than the main diagram, and therefore much easier to handle.

The repairman's tool box should always contain a main circuit fuse, a control circuit fuse, and a pump circuit fuse. The matter of locating trouble can be covered best by considering a typical so-called dead car. Assuming a case where the car is dead when the repairman arrives, he naturally thinks of the trolley voltage. Having assured himself, by turning on the car lights, that the voltage is on, he should check the following: main circuit fuse, control circuit fuse, the air at the switch group, which should be from 50 to 70 pounds. Operating the switches by hand will prove whether or not there is enough air at the group. The overload trip is checked to see that it is reset, and the trip contacts to see that they are clean and making contact with the disc. The master controller contacts and fingers, to see that none are broken and that they are making good contact with the drum. The control resistance to see that it is in good condition. The line relay contacts must be clean, and must close when voltage is applied to the coil. If air is leaking out of the magnet valve when the switch is open, the lower valve parts should be cleaned. If the leak occurs when the switch is closed, the upper valve parts should be cleaned. However, it is well to remember that it would have to be a very bad leak to prevent switch operation. If the car will run in one direction, and not in the other, it is probably due to the reverser not throwing. The reverser should be thrown by hand, and the wiring checked for open circuits when the car is in the barn. If the car will not accelerate, it is probably due to the limit disc not making contact. This may be due to dirt on the contacts, or it may be due to tight brakes which cause the car to take more than normal current, thus preventing the limit relay from dropping. The brakes should be repaired immediately, as running in this condition will burn up the grid resistance. If after cutting out a pair of motors, the car will not operate, the control contacts on the cut-out drum should be cleaned and checked for contact. A study of these conditions will enable the repairman to pick out those troubles which can occur in his particular equipment.

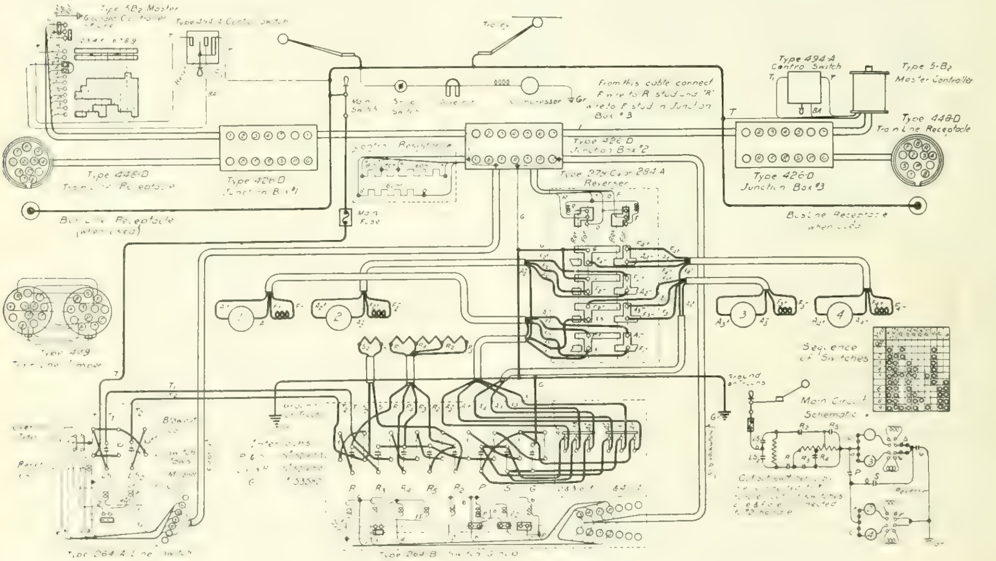


FIG. 8—COMPLETE WIRING DIAGRAM
Type HL unit switch control.

Use of Mica Insulation for Alternating-Current Generators

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Westinghouse Electric & Mfg. Company

Without mica the modern generating unit of twenty, forty and sixty thousand kilowatts capacity, developing energy at eleven, twelve and thirteen thousand volts, would be an unreliable machine, troublesome and expensive to its owner, and probably for its maker as well. The controversy as to the merits of mica insulation, which existed for many years, has now almost disappeared, as those who favored specially-treated tapes, have gradually become converts to its use.

In an industry which has grown from almost nothing to enormous proportions in the short space of thirty years, conditions peculiar to that industry generally exist. So it is with the electrical industry. Even today the science is not always exact and cut and try methods are sometimes resorted to. The larger manufacturers of alternators have unhesitatingly agreed to build larger and higher speed units, with consequent complication and difficulty of design, as the growth of the art demanded.

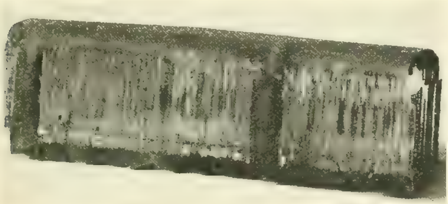


FIG. 1—EFFECT OF CORONA ON A PAPER CELL

The good qualities of mica have generally been recognized. It is admittedly a high heat resistant material, a good dielectric, and—of importance in the case of high voltage units—impervious to static. The objections to the use of mica have largely been related to cost. Mica of quality best suited for generator work must be imported. It comes in thin flakes of relatively small area and, therefore, requires mechanical support during application. It is somewhat inflexible and requires a stiff coil well braced against short-circuit stresses, where it projects beyond the core. Lastly, improperly applied mica insulation, is far worse than good tape insulation. Therefore, considerable shop equipment, skillful workmanship and experience in application are required for the best results.

The use of mica insulation for alternators dates back to 1895, when a most ambitious start toward the modern generating unit of large capacity was made by the building of vertical water-wheel driven machines of 5000 horse-power capacity each for use at Niagara Falls. To the designer, the problem was far beyond anything he had yet attempted, and a great deal of study was devoted to the choice of design and materials to be used. As evidenced by later day knowledge, the decision in favor of mica for insulation was a very wise one. A single copper bar, insulated with treated cloth and mica, formed the armature coil.

Eddy current losses in the large bars were responsible for winding temperatures considerably higher than the calculated I^2R losses. In time the treated cloth pulverized and in part disappeared. As it went, the natural springiness of the mica caused it to fill out the space left vacant, and held the coil tight in the slot. The dielectric strength of the coil was not seriously impaired, for after twenty years of service, it still withstood insulation tests of approximately five times normal operating voltage.* From the insulation standpoint these machines are still serviceable, although they will probably give way before long to units of almost ten times their size. Data gathered from the Niagara machines, and from others of that period, emphasized the necessity of splitting armature conductors into sections of relatively small area, the reduction in operating temperature and the increase in efficiency gained thereby, fully warranting the change in design.

For several years, partially closed armature slots were standard. Some coils were formed by threading round or rectangular wire through the slots, one turn at a time. Others had the straight core sections fully insulated and were pushed through the slots and separate connections made for the end turns or cross-connections. Generally both types had mica between the conductors and the core.

Gradually the theoretical advantages in performance of the closed slot type of machines were abandoned and the open slot type became general. A substantial reduction in winding costs and greater facility in making repairs were gained. Wooden or metal formers, hundreds of which were necessary for the many sizes of coils for different ratings and speeds, were superseded by the adjustable coil "puller", a single machine being capable of adjustment for the manufacture of many different coils. The present "diamond" shaped coil became standard for all but high speed turbogenerators which have a long coil throw.

As these decided improvements in insulation design were incorporated in newer machines, occasional operating difficulties were still encountered. What would have been absolutely safe and reliable for the old rat-

*See article on "Temperature Tests of Niagara Falls Generators" by T. Spooner, in the Journal for Apr. '16, p. 192.

ings and design proportions, was sometimes not quite good enough for the larger or the higher speed unit. Transmission systems became more complex, generating plants were gradually parallelled, then entire systems were tied together. Conditions external to the machines, and for protection against which the units were not, and sometimes could not be adequately proportioned were occasionally met.

For a long time, cotton only was used as insulation between adjacent conductors, and between parallel strands of the same conductor. Embedded temperature detectors disclosed facts regarding internal temperatures which no previous available methods of measurement had shown. Relatively high internal temperatures were reduced by a greater sectionalization of the coil and by better ventilation, and rendered less objectionable by the substitution of mica or asbestos for both conductor and strand insulation.

With generator voltages above 10 000 volts electrostatic stresses sufficiently high to break down air often occur, particularly at points and corners of ground potential such as the edges of projecting laminations and the edges of the core ventilating ducts. The "static" or corona that results is accompanied by the formation of nitrous oxide and nitric acid gases that affect some

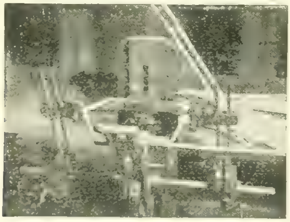


FIG. 2—PULLING MACHINE USED TO FORM ARMATURE COILS

insulating materials harmfully. Fig. 1 shows the effect of corona after one year's operation of a 12 000-volt generator on the paper cell used to protect the armature coil from the edges of the laminations during winding. It will be seen that the paper has been completely riddled with holes, each light line in the illustration representing a hole in the paper cell. The portions of the cell unaffected by the corona were adjacent to the air ducts. This generator was mica insulated (with a hand-wrapped mica-and-paper wrapper) and the armature coils themselves were unaffected by the corona. This generator has been in successful operation for over eight years.

When the first turbogenerators for supplying power for the New Haven single-phase electrification were built in 1907, the armature coils were insulated with treated cloth tape. These generators were operated at 11 000 volts with one terminal grounded which is equivalent, from an insulation standpoint, to a 19 000-volt generator with the neutral at ground potential. These first windings failed mechanically within a few months due to the large number of severe short-circuits. When the windings were removed it was found that disintegration of the treated cloth by corona had begun and it would have been only a matter of months before the windings would have failed from this cause. The generators were rewound with mica-insulated coils and during ten years' operation since no damage from corona has been experienced.

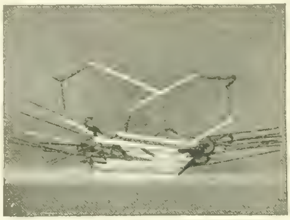


FIG. 3—COILS AFTER IMPREGNATION AND WITH HAND WRAPPED MICA WRAPPER APPLIED AND TAPED

These and many other instances have shown that cloth and paper insulations are very apt to fail if used in high voltage generators but that mica insulation is practically immune to the attacks of "static." In built-up mica and paper insulation the first layer of mica protects the paper underneath it.

A "corona protector" has been used in some cases with treated cloth insulations to minimize the harmful effects of corona upon this insulation. This consists of a metallic sheath of tinfoil tape wound spirally around the outside of the insulation on the straight parts of the coils. This tin foil is grounded at one end of the coil. This protector decreases the corona by bringing a uniform smooth surface at ground potential in close contact with the coil. At the beginning and end of each section of tin foil there is a concentration of stress and additional insulation is required at these points. If the ground connection is broken the protection is lost. If the continuity of the tape is broken the ends of the tape at the break are sources of danger. In investigating this point, it was found that a coil with tin foil broke down at the end of the tin foil at 29 500 volts and a duplicate coil, without the tin foil, broke down at 38 000 volts, an increase of nearly 30 percent. At best,

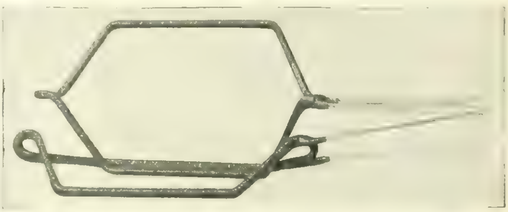


FIG. 4—COMPLETED DIAMOND COILS READY FOR MACHINE WINDING

the tin foil tape is bulky and occupies space that can be better used for copper or insulation.

The tin foil used as a protection against corona should not be confused with condenser type insulation. In the latter, concentric layers of tin foil are placed at intervals throughout the insulation and serve to dis-

tribute the electrostatic potential uniformly through the insulation. The grounded tin foil protector on the surface of the coil does not modify the distribution of potential through the thickness of the insulation; it modifies it only along the surface of the insulation.

Exceptionally rapid progress in insulation design has taken place in the past five or six years. Steam turbine units of fifteen, twenty or twenty-five thousand kilowatts have become quite usual. Waterwheel sets of ten, twenty and thirty thousand or more kilowatts are no longer viewed with distrust. The damage to units of such size when break-downs occur, and the great loss of revenue through their idleness, emphasize the practical necessity of the greatest care and experience in the building of that part of the machine which is so frequently the cause of shut-downs.

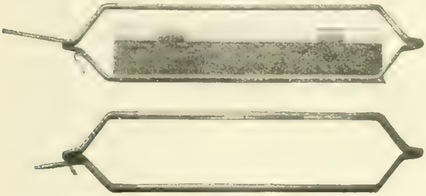


FIG. 5—TOP—PREPARING COIL FOR MACHINE APPLIED MICA WRAPPER BOTTOM—COMPLETED COIL

The latest types of armature coils may be divided into three general classes:—

1—Coils for service in machines having a relatively narrow core, in which the internal temperatures are not appreciably higher than those measurable by thermometer, and where the total maximum operating temperature will not exceed 105 degrees C. Cotton insulation, suitably impregnated, is suitable for both conductor and parallel strand insulation. A mica wrapper is used on the coil sides embedded in the armature iron, and treated tape over the end turns.

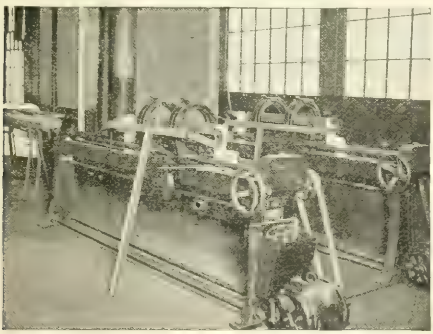


FIG. 6—MICA WRAPPER BEING APPLIED IN MACHINE

2—Coils for machines of high voltage, or having very wide cores or both, where higher internal temperatures may be found, should have both parallel strands and adjacent conductors insulated with mica tape over the entire periphery. A mica wrapper is used for insulation between coils and core on the straight sides, and treated tape on the end turns.

Copper wires or strands having a rectangular section are used for all but the very smallest alternators. This section gives greater current carrying capacity for equal space than a round wire, and it results in a stiffer and more rugged coil. The wires may be formed over a coil former, or the number of turns wanted wound on a shuttle and pulled to the final shape of the coil in a coil puller, as shown in Fig. 2.

Wires may be cotton covered or bare, depending on the grade of coil wanted. If cotton covered, after forming they are impregnated, or first treated with Bakelite, and then impregnated. If bare, they are insulated by hand with mica tape after the forming or pulling process, then bakelized and impregnated.

The impregnating process is a combined heat and vacuum one. The coils are put into tanks, the air is exhausted from the tank, and well heated and softened varnish gum forced in. This process is designed to eliminate air pockets from between turns, and to substitute a gum, which is a better heat conductor.

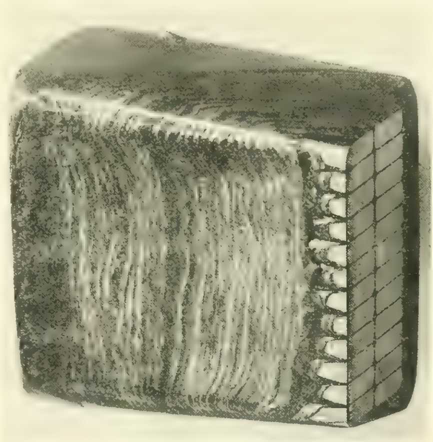


FIG. 7 SECTION OF A 12 000 VOLT, MACHINE WRAPPED, MICA INSULATED COIL

Insulation bevelled off showing percentage of mica used and tightness of application. Light colored lines are mica; the darker lines between are the mechanical paper support.

A mica wrapper is then applied to the straight sides of the coil, or those sections which go into the armature slots. For 2400 volt service or lower, this consists of a special paper on which thin flakes of mica have been pasted. It is wrapped as tightly by hand as is possible, and a retaining layer of tape is bound on. The end turns are well insulated with treated tape and the joint between the mica and the tape is sealed with varnish. A slight taper at the joint simplifies and improves this operation.

Where a relatively thick wall of insulation is required between conductors and core, as for 6600, 11 000, 13 000 volt machines, the insulation has its heat

radiating characteristics improved and the wall made slightly thinner by applying the wrapper by machinery. The machine wrapper is similar to that used for the hand process, except that the paper backing can be somewhat thinner, so that the percentage of mica to paper is increased. After applying the wrapper loosely by hand, the coil is set up in a machine, and electrically-heated arms soften the shellac coating and exert a uniform pressure while revolving around the coil side, as shown in Fig. 6. The end turns are taped and sealed as before.

Both types of coils, that is with hand and machine applied wrappers, are pressed and calipered accurately to size to fit snugly into the armature slots inside a heavy paper cell. After winding into slots the end turns are well tied and braced against distortion.

Electricity in Celluloid Manufacture

E. W. Manter
Boston District Office,
Westinghouse Electric & Mfg. Company

The manufacture of celluloid articles requires the application of considerable heat to soften the celluloid stock during certain of the manufacturing processes, as the stock can be worked properly only at temperatures varying from 165 to 190 degrees F. according to the nature of the operation. When so heated the celluloid is pliable and may readily be chiseled, molded or stamped as occasion requires.

For the heating of this material many manufacturers have used flat steam tables, supplied with steam at 50 lb. pressure. The steam tables are liable to cause considerable trouble, however, due to lack of suitable temperature control and there is also frequent trouble with steam condensation, which causes flooding, making it difficult to obtain uniform temperatures. These operating difficulties, together with the scarcity and

FIG. 1—ELECTRIC HEATING TABLE

poor quality of fuel during the winter of 1917-1918 caused the Ideal Comb Co. of Lowell, Mass. to experiment with electric tables. They made arrangements to purchase power from the Lowell Electric Light Corporation and obtained a 16 by 24 inch electric table having three heat control with current consumptions of 1800, 900 and 450 watts respectively. The successful operation of this table soon led to the installation of eleven similar tables. As it is necessary to heat the celluloid for every operation, the tables were distributed in the embossing, chiseling and finishing departments. These electric tables can be heated to working temperatures in ten minutes and can be maintained at any one of the three operating temperatures with practically no temperature fluctuations.

This factory manufactures combs, barrettes and imitation tortoise shell eye glass rims from flat celluloid stock. In the manufacture of straight combs, large sheets of flat celluloid stock about 0.125 inch thick are sheared into flat pieces of eight or nine inches long and about 2.25 inches wide. A piece of this size is sufficient for two combs. The next operation is embossing, in preparation for which a number of pieces are heated on the electric tables. When these pieces have reached the proper temperature they are placed in the die of the power press, which embosses a design on either or both sides. These embossed pieces are now ready for the chiseling machines. They are heated again to a pliable state on electric tables and are run through the chiseling machine. This machine has a vertical knife which cuts the celluloid to form two

FIG. 2—EMBOSSING PRESSES WHICH PRESS THE DESIGN ON THE DOUBLE COMB BLANK

combs dovetailed together, which are readily stripped apart, while the material is still warm. By this method only two small pieces of stock at the ends are wasted.

The next operation is called "burring" for which no heat is necessary. The so called "burr" used for this operation is a circular cutter having five circular cutting blades which smooth five comb teeth at a time. With this tool the teeth are tapered down to a blunt point. The combs are then polished, which on certain classes of work is done with rag wheels and on others with a chemical bath, whose chief component is acetic acid. When combs are polished chemically they are dipped in the solution and dried in a large wooden compartment which has steel clad electric heaters at the bottom, furnishing a very mild heat. After this dry-

ing process the combs are ready to be packed for shipment. Curved combs are subjected to another heating process, preliminary to the bending operation shown in Fig. 4.

The principal saving produced by the use of the electric heaters is time. In the embossing operation

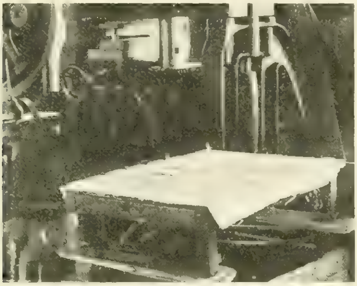


FIG. 3—HEATING THE FLAT STRIPS ON THE ELECTRIC TABLE BEFORE EMBOSSING THE DESIGN

an operator who formerly turned out 12 gross per day on the steam table, increased his production to 14 gross per day, also reducing the spoilage by more than half.

Owing to the better temperature control of the electric tables, the manufacturers also found that they could use lighter weight stock and secure equally good results. For example 0.14 inch thick flat was formerly used

FIG. 4—ELECTRIC TABLES REHEAT THE BLANKS WHICH HAVE BEEN EMBOSSED IN READINESS FOR THE CHISELING MACHINE

to manufacture large combs;—now they are using stock of 0.125 inch thickness, which produces a considerable saving in raw material.

To determine the cost of operating an electric table, the Lowell Electric Light Corporation connected a single-phase watthour meter with the trial table. This table was operated continuously on medium heat for certain work and on low heat for lighter work. As a result of several days test it was found that the cost of operating on medium heat all day was 17 cents and on low heat 9 cents. The rate for electric heating was the same as their power rate which averaged 2.25 cents per kw-hr. The total cost of current used in making combs by electric heat did not exceed three cents per gross. Tests to determine the uniformity of heat secured with a table which had been in operation several

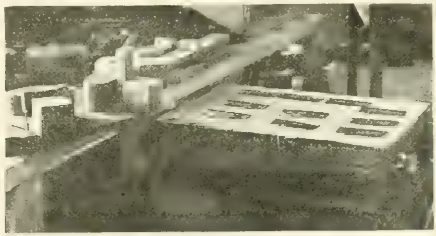


FIG. 5—HEATING COMBS IN ORDER TO BEND THEM OVER THE WOODEN FORMS SHOWN ON THE BENCH

months showed that the widest variations in temperature in a three hour test did not exceed 1.5 percent.

With respect to economy of operation, the Hon. James B. Casey, treasurer of the Company stated that

FIG. 6—HEATING THE OVAL BLANKS USED FOR STAMPING OUT BARRETTE FRAMES

by installing electric drive and electric tables, he had reduced the operating expenses by more than one-half. In addition, the production has increased 25 percent and spoilage is now reduced to a minimum, solely through the adopting of electric tables.

Essentials of Transformer Practice-XX

Three-Phase to Two-Phase Transformation with Single-Phase Transformers Scott Connected

E. G. Reed

THE Scott connection is the one most commonly used for a three-phase to two-phase transformation. Its main advantages are that practically standard transformers are used, only two units are required, and the excess of transformer capacity required over the k.v.a. transformed is not great. The main and teaser units required for the transformation can be made duplicates of each other, and thus interchangeable without great additional expense. The practical importance of this connection therefore warrants the following analysis as to the voltage regulation secured under load conditions.

The vector relations of the voltages and currents for a three-phase to two-phase transformation are shown in Fig. 1. With a load having a 100 percent power-factor the voltage and current in the teaser transformer are in phase, but in the main unit the voltage and current are 30 degrees out of phase. For this

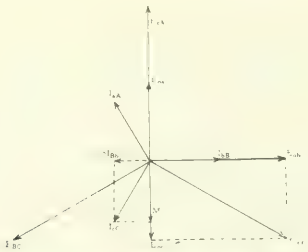


FIG. 1—TWO TRANSFORMERS SCOTT CONNECTED FOR THREE-PHASE TO TWO-PHASE TRANSFORMATION

Showing vector relations of voltage and currents, with a ratio of voltage transformation of unity. Vector M represents the current in the three-phase winding which balances the two-phase current I_{E} in the main transformer.

reason the ratio of the k.v.a. of transformer capacity required to the k.v.a. transformed is greater than unity. The current in the main transformer I_{cC} may be thought of as being made up of the two components $0.5\ I_{ab}$ and the current at right angles to $0.5\ I_{Bb}$ which counterbalances the current I_{Ee} on the two-phase side of the main transformer. The current I_{aA} is also made up of two similar components.

Fig. 2 shows the two transformers connected for the three-phase to two-phase transformation. Assuming a balanced load on the transformer group, the currents in the three-phase and two-phase windings are,—

$$I_{bB} = \frac{K.v.a.\ transformed}{1.73\ E_3}$$

and

$$I_{aD} = \frac{K.v.a.\ transformed}{2\ E_2}$$

Where E_3 is the voltage on the three-phase side and E_2 the voltage on the two-phase side. Combining these two equations gives,—

$$I_{bB} = \frac{2}{1.73}\frac{E_2}{E_3} I_{aD} = 1.155 \frac{E_2}{E_3} I_{aD} \ldots\ldots\ldots\ldots\ldots (1)$$

The transformer capacity required for this transformation is equal to the sum of the products of the voltage and currents for the several parts of the windings.

$$K.v.a.\ rating\ of\ three\text{-}phase\ side\ of\ group = E_3\ (I_{bB} + 0.866\ I_{bB}) = 1.866\ E_3\ I_{bB}$$

$$K.v.a.\ rating\ of\ two\text{-}phase\ side\ of\ group = 2\ E_2\ I_{aD}$$

$$Total\ K.v.a.\ rating\ of\ grouping = \frac{1.866\ E_3\ I_{bB} + 2\ E_2\ I_{aD}}{2}$$

Substituting in this expression the value of I_{bB} from equation (1), gives,—

$$Total\ K.v.a.\ rating\ of\ group = \frac{1.866\ E_3\ 1.155 \frac{E_2}{E_3} I_{aD} + 2\ E_2 I_{aD}}{2} = 2.077\ E_2\ I_{aD}$$

$$The\ k.v.a.\ transformed = 2\ E_2\ I_{aD}$$

And

$$\frac{Total\ k.v.a.\ rating\ of\ group}{K.v.a.\ transformed} = \frac{2.077\ E_2\ I_{aD}}{2\ E_2\ I_{aD}} = 1.04 \ldots\ldots (2)$$

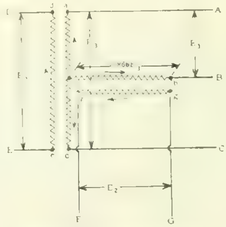


FIG. 2—TWO SCOTT CONNECTED TRANSFORMERS FOR THREE-PHASE TO TWO-PHASE TRANSFORMATION

If the two transformers are identical, that is, interchangeable with each other, then,—

$$Total\ k.v.a.\ of\ group = \frac{2\ E_3\ 1.155 \frac{E_2}{E_3} I_{aD} + 2 E_2 I_{aD}}{2} = 2.155\ E_2\ I_{aD}$$

Then,—

$$\frac{Total\ k.v.a.\ rating\ of\ group}{K.v.a.\ transformed} = \frac{2.155\ E_2\ I_{aD}}{2\ E_2\ I_{aD}} = 1.077 \ldots\ldots (3)$$

The regulation of a Scott-connected group of transformers is a matter of some importance and it may be determined in a manner similar to that used for the two transformers connected in open delta. The impedance values necessary to determine the regulation might be measured under the actual conditions of two-phase to three-phase transformation, but it is more usual to base the calculations on the single-phase measurements made under the proper conditions on the transformers. These single-phase impedances can also be approximately calculated more easily than the three-phase impedances, if the required design data are at hand.

In the circuit BC Fig. 2, there are three imped-

ances. The first is through the teaser transformer, and is the normal impedance of the transformer measured with a single-phase current equal to I_{bB}. The other two impedances are in the main transformer. The first of these can be measured with a single-phase current

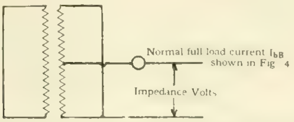


FIG. 3—CONNECTION FOR DETERMINING THE IMPEDANCE OF THE MAIN TRANSFORMER IN THE SCOTT CONNECTION

equal in value to I_{bB}, and with the connection shown in Fig. 3. This measurement gives the impedance drop through each half of the main transformer with the current 0.5 I_{bB} in each half, and is the vector sum of the resistance drop in each half and the reactive element due to the magnetic separation of the two halves of the winding on the three-phase side with respect to each other. The third impedance drop is one-half of that in the main transformer measured with a current in the two-phase side, equal to that flowing in that winding under normal operating conditions. The impedances in the phase AB are the same as those in the phase BC. The impedance in the phase CA is that of the main transformer, measured with the normal operating current in the two-phase winding.

Let these three impedances be expressed vectorially as follows

1—Single-phase impedance of the teaser transformer, measured with the current I_{bB} in the three-phase winding,—

$$IZ_1 = IR_1 + IX_1 \qquad (4)$$

2—Single-phase impedance of the main transformer measured as shown in Fig. 3, with the current 0.5 I_{bB} in each half of the three-phase winding,—

$$IZ_2 = IR_2 + IX_2 \qquad (5)$$

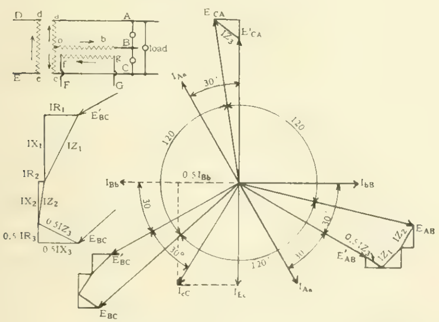


FIG. 4—VECTOR RELATIONS FOR A TWO-PHASE TO THREE-PHASE TRANSFORMATION

On the three-phase side, for a load having a 100 percent power-factor, with a ratio of voltage transformation of unity. An enlarged diagram of the vectors between E_{BC} and E'_{BC} is shown at the left drawn to scale for the values given in the example.

3—Single-phase impedance of the main transformer measured with normal operating current in the two-phase winding,—

$$IZ_3 = IR_3 + IX_3 \qquad (6)$$

The impedance in phases BC and AB is $IZ_1 + IZ_2 + 0.5\, IZ_3$, and the total drop in voltage across the phase BC, for example, is the vector sum of the three impedance triangles in this phase, shown in Fig. 4. The vector E_{BC} is the voltage of this phase at no load and E'_{BC} is the voltage of the same phase at normal full load. Since the resistance drop components of the impedance triangles in phase BC are in phase with the currents I_{Bb} and I_{Ee} respectively, the phase relation of the voltage E'_{BC} and the IR component of the equivalent impedance triangle across the phase BC can be determined. In the symbolic notation, for this phase,—

$$IR = IR_1 + IR_2 + j\, 0.5\, IR_3 \qquad (7)$$

$$IX = IX_1 + IX_2 + j\, 0.5\, IX_3 \qquad (8)$$

Therefore the regulation of phases BC and AB, by the use of equations (11) and (12), Section VI, is,—

$$IR \cos \phi \pm IX \sin \phi \qquad (9)$$

The angle ϕ as shown in Fig. 5 is that between the IR component of the equivalent impedance triangle and the voltage vector E'_{BC}. In order to determine this

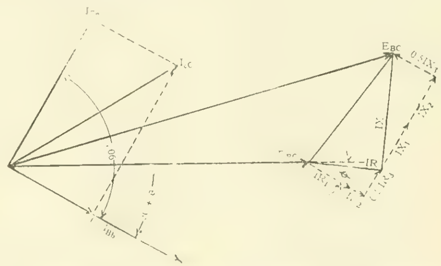


FIG. 5—VECTOR RELATIONS OF THE VOLTAGES AND CURRENTS OF THE PHASE BC

To an enlarged scale, for a load whose power-factor is cos. θ.

angle ϕ, the angle between IR_1 and IR must be known. This angle is,—

$$\tan^{-1} \frac{0.5\, IR_3}{IR_1 + IR_2}$$

and therefore,—

$$\phi = \theta + 30^\circ - \tan^{-1} \frac{0.5\, IR_3}{IR_1 + IR_2} \qquad (10)$$

where θ is the angle whose cosine is the power-factor of the load. In equation (9) the minus sign is used when the vector IR is ahead in phase relation of the voltage E'_{BC}, and the plus sign where IR is behind E'_{BC} in phase.

The impedance in the phase CA is IZ_3, as shown in Fig. 4. The resistance drop component of the impedance is in phase with the current I_{eE}. The regulation of this phase is,—

$$IR_3 \cos \theta \pm IX_3 \sin \theta \qquad (11)$$

where θ is the angle whose cosine is equal to the power-factor of the load. The minus sign is used when the IR_3 component of the impedance drop is in advance of E'_{CA} in phase and the plus sign when it is behind E'_{CA} in phase relation.

Example—What is the regulation on the three-phase side of a Scott-connected group of transformers, when the resist-

ance and reactive drops under this condition are expressed in percentages as follows,—

$$IR_1 = 1.6 \qquad IX_1 = 3.2$$
$$IR_2 = 0.2 \qquad IX_2 = 2.0$$
$$IR_3 = 1.7 \qquad IX_3 = 3.5$$

and for a balanced load having power-factor of 80 percent?

From equations (7) and (8),—

$$IR = \sqrt{(1.6 + 0.2)^2 + \left(\frac{1.7}{2}\right)^2} = 1.97\ percent.$$

$$IX = \sqrt{(3.2 + 2.0)^2 + \left(\frac{3.5}{2}\right)^2} = 5.49\ percent.$$

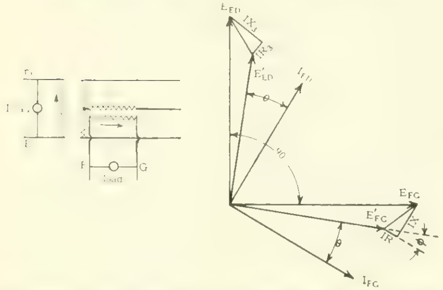


FIG. 6—VECTOR RELATIONS FOR A THREE-PHASE TO TWO-PHASE TRANSFORMATION

On the two-phase side, for a load whose power-factor is cos. θ.

From equation (10),—

$$\phi = 37^\circ + 30^\circ - tan^{-1}\frac{0.5 \times 1.7}{1.6 + 0.2} = 42^\circ$$

From equation (9) the regulation is,—

$$1.97 \times 0.743 + 5.49 \times 0.669 = 5.14\ percent.$$

The regulation of phase CA from equation (11) is,—

$$1.7 \times 0.8 + 3.5 \times 0.6 = 3.46\ percent.$$

If the two halves of the three-phase winding on the main transformer were not properly interconnected, (Fig. 7 shows the correct interconnections.*) IX_2 would be greatly increased in comparison with the value used in the above example. The calculations indicate that if IX_2 is increased, the regulation of phases BC and AB would be poorer, and also that the regulation of phase CA would not be affected.

This reasoning regarding regulation is based on the assumption of balanced three-phase voltages delivered by the transformers at no load, and a balanced three-phase load. Under these conditions the vector sum of the three load voltages at full load would be equal to zero, and consequently the vector sum of the impedance drop in the three-phases would be also equal to zero. That this is true is evident from a study of the impedance triangles in the three phases in Fig. 4.

An examination of Fig. 6 indicates that the regulation of the phase ED is the same as the regulation of the phase CA on the three-phase side. The impedance in the phase FG is the same as that in the phases BC and AB on the three-phase side. Therefore, the regulation of phase FG, is

$$IR\cos\phi \pm IX\sin\phi \quad \ldots\ldots\ldots\ldots\ldots\ldots (12)$$

when IR and IX are given by equations (7) and (8). The angle ϕ between the IR component of the equivalent impedance triangle and the voltage E'_{FG} is

$$\phi = \theta - tan^{-1}\frac{0.5\ IR_3}{IR_1 + IR_2} \ldots\ldots\ldots\ldots\ldots\ldots (13)$$

The minus sign in equation (12) is used when IR in Fig. 6 is in advance of the voltage E'_{FG} in phase relation and the plus sign when it is behind E'_{FG} in phase.

Example—What is the regulation on the two-phase side of a Scott connected group of transformers, when the resistance and reactive drops under this condition are,—

$$IR_1 = 1.6 \qquad IX_1 = 3.2$$
$$IR_2 = 0.2 \qquad IX_2 = 2.$$
$$IR_3 = 1.7 \qquad IX_3 = 3.5$$

and for a balanced load having an 80 percent power-factor?

The regulation of phase ED is the same as for the phases CA on the three-phase side in the preceeding example or 3.46 percent. For the phase FG the regulation is calculated as follows,—

From equation (13) the angle $\phi = 37^\circ - 25^\circ = 12^\circ$

From equation (12) the regulation is

$$1.97 \times 0.978 + 5.49 \times 0.208 = 3.07\ percent.$$

It is apparent that a large increase in the value of IX_2 resulting from improperly interconnected windings would not change the regulation of phase ED on the two-phase side, but would increase the regulation of the phase FG.

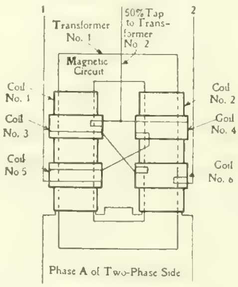


FIG. 7—INTERCONNECTIONS OF COILS ON A CORE TYPE TRANSFORMER For three-phase—two-phase transformation.

A summary of the regulation calculated for the two examples given is,

For Three-Phase Side

a—For phase BC, 5.14 percent.
b—For phase AB, 5.14 percent.
c—For phase CA, 3.46 percent.

For Two-Phase Side

a—For phase ED, 3.46 percent.
b—For phase FG, 3.07 percent.

*See article by the author on "Magnetic Leakage in Transformers" in the JOURNAL for May, 1910, p. 396, from which Fig. 7 is repeated.

Three-Phase Four-Wire Distribution

Geo. E. Wagner
Superintendent of Plants,
Madison (Wisc.) Gas & Electric Company

THREE-PHASE current was at first distributed over three-wire circuits. In this system transformers for lighting purposes are connected between any two lines and for three-phase power they are connected in delta on both primary and secondary side. This connection is shown on Fig. 1 and is generally referred to as the delta-delta connection.

Shortly before 1900, three-phase, four-wire distribution was developed, increasing the line voltage, thereby reducing the size of wire and the amount of copper required, and still permitting the use of the same step-down transformers used for the three-wire system. In this system, the transformers for polyphase use are connected in star on the primary and in delta on the secondary side, Fig. 2, generally called the star-delta connection. The voltage on the transformers is the same as on the three-wire system and therefore the secondary voltage is also the same. For single-phase use transformers are connected between a phase wire and the neutral as shown in Fig. 3, the neutral point being grounded.

Since 1900 the three-phase, four-wire system has been adopted by many cities which have remodeled their distribution system or have developed new systems.

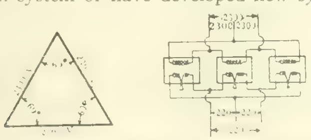


FIG. 1—THREE-PHASE DELTA—DELTA SYSTEM

At the present time there are still three methods of distributing high-voltage alternating current, namely: single-phase, two-phase and three-phase. In both two-phase and three-phase there are three-wire and four-wire systems. In comparing these various methods of distribution it is essential first to consider the first cost, the largest item of which is the copper. Assuming the weight of copper required for a single-phase circuit as 100 percent, the amount of copper required for the various systems for the same load would be as follows:

Single-phase system	100 percent
Two-phase four wire system	100 percent
Two-phase three-wire system	73 percent
Three-phase three-wire system	75 percent
Three-phase four-wire system	33 percent

The above tabulation assumes that the same step-down transformers will be used with all the systems; *i. e.* that the voltage between conductors, in case of single-phase, two-phase four-wire and three-phase three-wire systems is the same as the voltage to neutral of the three-phase four-wire system. Hence in the three-phase four-wire system the voltage between phase conductors is increased $\sqrt{3}$ times, requiring only one-third of the copper of a three-phase three-wire system or 25 percent of a single-phase circuit carrying the same amount of power. However this does not include the fourth or neutral wire. If this wire has a section equal to either of the three-phase wires, the copper is increased from 25 to 33 percent.

The three-phase, four-wire distribution in general use is the 2300/4000 volt system, so called because the voltage between any phase wire and the neutral point or neutral wire is about 2300 volts and between phase wires 4000 volts. Since the voltage to neutral is the same as was used for the three-wire system, the same transformers can be used.

Since the line voltage in the four-wire system is 1.73 times that of the three-wire system, the line current is proportionately less and the line drop is directly proportional to the line current, it follows that the size of wire required for the same load and with the same permissable loss is one-third of that required for three-wire distribution. It follows that if a three-wire circuit is converted into a four-wire circuit the capacity of the circuit is tripled. If this circuit is to supply any individual single-phase transformers, however, then the fourth or neutral wire should be strung in. It is possible to use the ground as the neutral return, but it is more satisfactory to use a fourth wire.

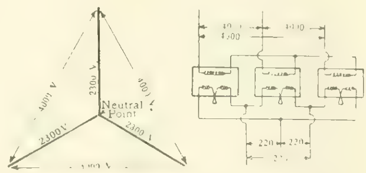


FIG. 2—THREE-PHASE STAR-DELTA SYSTEM

From the above it also follows that if two single-phase circuits are combined into one four-wire three-phase circuit, the capacity of the three-phase circuit is three-times that of the two single-phase circuits combined. For example, the amount of electric energy will be calculated that can be transmitted a distance of 5000 feet over No. 2 copper wire with a line drop of 92 volts between the generator and the load, the phase voltage to be 2300 volts. The resistance of No. 2 copper wire is 0.156 ohms per 1000 feet and the resistance of one single line would be five times that or 0.78 ohms.

In a single-phase circuit the drop in voltage would be twice the drop in one line. Assuming that only the resistance drop is considerable, the circuit would then transmit $92 \div (0.78 \times 2)$ or 58.9 amperes or about 135 k.v.a.

In a three-phase, three-wire circuit, the drop in voltage would be 1.73 times the drop in one line. A

circuit of No. 2 wire would then transmit 92 ÷ (0.78 × 1.73) or 68.2 amperes or about 270 k.v.a.

In a three-phase four-wire circuit with a balanced load, the drop in voltage would be the drop in one line only. This circuit will then transmit 92 ÷ 0.78 or 118 amperes or about 810 k.v.a.

Since the number of wires required for the above systems are 2, 3 and 4, respectively, the amount of copper required under the three conditions would be in the ratio of 2 to 3 to 4. The calculations show, however, that the amount of power that can be transmitted varies in the ratio of 2 to 4 to 12.

While the increased line voltage is advantageous in so far as it requires less copper it must be viewed from another angle not so beneficial. If branches of trees are permitted to extend through the line between phase wires, they will cause leakage particularly in wet weather, frequently causing one or more wires to burn off. For the same reason, larger line insulators are usually required. The increased voltage, must also be taken into consideration on underground work. The grounded neutral and increased line voltage must also be considered in the choice of lightning arresters. On account of the grounded neutral, a ground on a phase wire will cause a short-circuit.

When linemen work on a three-phase four-wire circuit they must bear in mind that they are working on a higher voltage than on a three-wire line with the same voltage for transformers. The grounded neutral protects the circuit against a possibility of a voltage higher than the phase voltage to ground. This should therefore be considered as a safeguard and no disadvantage.

In both three-wire and four-wire systems it is possible to supply three-phase current from two transformers only, with an open delta secondary. If, only two transformers are used on a four-wire circuit the middle point of the transformer bank must be connected with the neutral wire. Without this connection the two transformers would simply be in a series across 4000 volts and would deliver a single-phase current only. Either the primary or the secondary of one transformer must also be reversed, to secure the proper phase relations.

When three transformers are used on a four-wire circuit, the neutral point of the transformer bank should be isolated, except in special cases, that is, it should have no connection with the neutral wire of the circuit or the ground.*

Some companies have tried to connect the primary neutral point of transformer banks which supplied a comparatively large single-phase load in addition to a three-phase load, to the neutral wire, a larger transformer being installed in the phase supplying the single-phase load to take care of the unbalance. The primary neutral wire was connected with the idea that it would take care of the excess primary current for the larger transformer instead of having it pass through the windings of the smaller transformers. An example of this condition would be a consumer requiring single-phase current for spot welders and three-phase current for a few motors.

Laboratory tests have demonstrated that under the conditions cited above the primary neutral carried practically no current. The tests showed that if a single-phase load is supplied from one phase of a three-phase bank of transformers, the other two transformers act as one single-phase transformer operating in parallel with the one on the loaded phase and share the load with it. The oscillograph showed that the current through the primary winding of the large transformer divided and part of it passed through the primary winding of each of the other two transformers. The current waves of the current in the two transformers were about the same, exactly in phase and just 180 electrical degrees from the current in the transformer on the loaded phase.

These tests also showed that the current in the neutral wire was practically zero so long as the voltages were balanced. As soon as the voltages were unbalanced in the secondary delta a circulating current was set up in the delta and there was a flow of current in the neutral wire of the primary current.

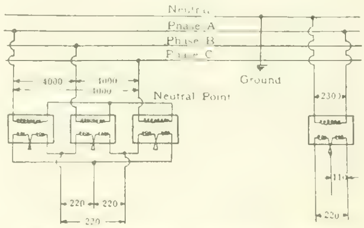


FIG. 3—THREE-PHASE FOUR WIRE SYSTEM
Showing bank of three single-phase transformers and one single- phase lighting transformer.

When a single-phase load was supplied from one phase of delta connected secondaries, during these tests, the load was distributed over the three transformers, the transformer on the loaded phase supplying about one-half and the other two together the other half. The exact proportions of the load supplied by each seemed to depend upon the power-factor of the circuit. The tests also showed that the three transformers divided the single-phase load in about the same proportion whether the primary neutral was connected or isolated.

The results of these tests were verified in the field on a bank of transformers supplying a 200 ampere three-phase load and in addition two 100 ampere spot welders from one-phase. Every time a spot welder came on it drew current from all three transformers. The current in the neutral caused by the welders coming on was practically nothing. A comparatively heavy current was set up in the neutral wire, however, when

*See Article on "A Study of Three-Phase Systems," by Chas. Fortescue in the JOURNAL for Sept. 1914, p. 464.

the operator at the station varied the voltage on one phase with the feeder regulator.

From the above it follows that in a bank of transformers to supply three-phase power and an additional single-phase load there is no occasion for installing one transformer with a capacity larger than the capacity of the other two combined. Inasmuch as the neutral wire carries practically no current there would be, under such conditions, an excess current in the windings of one or both of the smaller transformers, if the larger transformer carried full load. In determining the sizes of transformers necessary for an installation like the above it should be borne in mind that the transformer on the phase supplying the single-phase load actually supplies only about one-half of the single-phase current while the other two supply the balance.

From the above it also follows that the primary neutral point of three-phase transformer banks should be isolated unless the transformers have ample capacity to take care of their regular load plus any circulating current that may be set up on account of an unbalanced voltage condition. If one-phase wire should develop a ground the voltage on that phase would naturally drop on account of the heavy current. The transformer bank

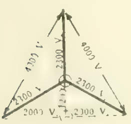


FIG. 4—DISTORTION OF STAR SYSTEM

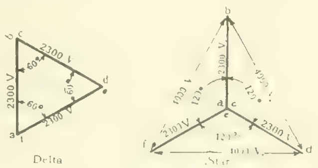


FIG. 5—VOLTAGE MAGNITUDES AND RELATIONS IN THE DELTA AND STAR SYSTEMS

with the primary neutral connected would immediately tend to equalize the voltages on the three phases. The other two transformers would draw a heavy current on their phases trying to boost the voltage on the grounded phase. The probable result would be that the primary fuse of one transformer would blow and the other two would then carry the load on open delta. If the capacity of the other two transformers was insufficient they would be overloaded and would be liable to be damaged.

If the primary neutral point of a transformer bank is isolated, there is no circulating current caused by unbalanced voltages but if one blows a fuse the other two transformers are actually in series between two phase wires. Their secondary voltages are then one-half of the normal voltage times 1.73 (about 200 instead of 230) and the voltage across the secondary and primary of the transformer with the fuse blown is zero when the load is straight resistance or single-phase load. If there are any three-phase motors on the circuit they will run and their windings will tend to keep up a delta voltage. If these motors are stopped they will as a rule not start because it would be equivalent to trying to start them on single-phase current.

One of the greatest advantages of three-phase four-wire distribution is its successful use for both light and power purposes regardless of load balance. If a single-phase feeder regulator is installed in any phase, it can be adjusted to give a constant voltage at any point on the line regardless of the load on the other phases. In fact, one method of developing a four-wire circuit is to supply all the single-phase lighting load from one phase and equip this phase with a feeder regulator. When the lighting load increases it can be distributed over all three phases and feeder regulators installed in them.

On account of the simplicity of voltage regulation a three-phase, four-wire circuit can be used for supplying all the current for any district, whether it is used for lighting, heating or power. It thereby overcomes the necessity of paralleling circuits and investment for any district. Supplying current for both lighting and power purposes also increases the load factor on the circuit, because the power load is generally quite low before the lighting peak comes on.

In three-phase, four-wire distribution, individual transformers for lighting purposes are connected between any one phase wire and the neutral wire. If a number of such transformers are distributed over the three phases there is a possibility of trouble from another source. Under this condition the current in the neutral wire is the vector sum of the current in the phase wires. If the neutral wire should open between the station and the load, an unbalanced load on the phases would cause an unbalance in voltage which might be disastrous to lamps burning in the circuit at the time.

The current in the primary winding of a transformer increases as the secondary current increases because the actual reactance in the primary decreases. Therefore if two phases were heavily loaded and one phase had almost no load and the neutral wire was broken, the difference in reactance would cause the neutral point of the circuit to be drawn out of center, as shown by circles in Fig. 4. The transformers on the loaded phases would then practically be in series between phase wires and would deliver a secondary voltage of nearly 100 and 200 instead of 110 and 220 volts. The transformers on the phase carrying very little load would have a voltage of about 3500 volts impressed upon their primary and their secondaries would deliver 175 and 350 volts instead of 110 and 220 volts, with the probability of burning out some lamps. In Fig. 4 the correct voltages are indicated by full lines and the distorted voltage condition is shown by the dashed lines.

The probability of such a case of trouble is quite remote. The effect of such an occurance can be reduced by carefully distributing individual lighting transformers over the three-phase with a view of keeping the load fairly well balanced. The possibility of such a case of trouble can be overcome by supplying all of the single phase lighting transformers from one phase but the most satisfactory method of overcoming this danger

seems to be to ground the neutral wire not only at the station but at several places along the line. The ground connections would serve as a path in parallel with the neutral wire and if the neutral wire broke down anywhere the ground would take care of the unbalanced load and prevent sufficient distortion to do any damage. Special care should be taken in the selection of the points for grounding to guard against picking up stray currents. It would be an aid in this direction to connect the neutral wires of different circuits as a guard against having any entirely down at any time. The neutral wire should never be fused and should have no switches, except four-pole, which will open all four wires at once.

In changing from three-phase, three-wire to three-phase, four-wire distribution the first consideration is, of course, the higher voltage generator. If the winding of a 2300 volt, three-phase generator is connected in delta, it can be connected in star and if the insulation is sufficient, can be used for 4000 volts. If the generator is already star connected it would have to be rewound, or delta-star transformers used.

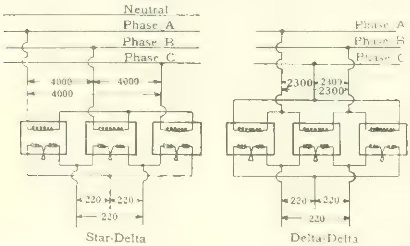


FIG. 6—THREE-PHASE FOUR-WIRE AND THREE-PHASE THREE-WIRE SYSTEMS

With transformers connected for three-phase service.

The all important requirement on the line is to make sure that when the change is made in the transformer connections the phase relations will not be changed, in order that the rotation of three-phase motors will not be reversed. Fig. 5 shows the change from delta to star connection which will not disturb the phase relations. Fig. 6 shows the actual change in connections in the field in changing a bank of transformers from delta-delta to a star-delta. The connections on the secondary side are not disturbed. The simple rule is that all the right hand primary side or all the left hand primary side are connected to the neutral point and the other sides are connected to phase wires.

It might be well to caution against reversing the secondary side of any one transformer in connecting a new bank. Such a connection would produce a short-circuit on a voltage equal to twice the phase voltage. This condition is shown in Fig. 7. An attempt to close the secondary delta with the primary current on it would cause a short-circuit on 440 volts.

SUMMARY

1—On account of the increased voltage in the three-phase, four-wire system, the amount of copper required for transmitting the same load over the same distance is very much less than is necessary for any of the other systems.

2—The change to the four-wire system does not cause a change in voltage of the stepdown transformers, thereby permitting the use of the same transformers.

3—The four-wire system can, on account of the star connection and its simplicity of regulation, be used for supplying current for light, heat and power purposes from one circuit, thereby overcoming the necessity of parallel circuits. This produces an additional saving in copper.

4—In order to protect all parts of the circuit against excessive voltage to ground and to protect single-phase lighting transformers against excessive voltage, the neutral wire of a three-phase, four-wire circuit should be grounded not only at the station but at a sufficient number of points along the line.

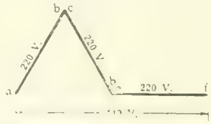


FIG. 7—EFFECT OF REVERSING PHASES ON THE SECONDARY DELTA

5—The neutral point of three-phase transformer banks should be isolated.

6—When the neutral point of a three-phase transformer bank is connected with the neutral wire of the circuit, the delta connected secondaries tend to equalize the phase voltages. This should therefore not be done, except on transformers of large capacity for a special purpose.

7—If a single-phase load is supplied from one phase of the delta connected secondaries of a three-phase bank of transformers, the transformer on that phase will supply about one-half of the single-phase current and the other two transformers will supply the balance, whether the primary neutral point is connected to the neutral wire or not.

In conclusion it might be well to emphasize that the principal advantage of three-phase four-wire distribution is the combination of the increased line voltage and star connection. The star connection without an increased line voltage would require as much copper as a single-phase circuit. The increased voltage without the star connection would sacrifice the simplicity of regulation and consequent advantage for supplying current for light, heat and power from one circuit.

Three-Phase to Two-Phase Transformation

J. B. Gibbs

NUMEROUS schemes have been proposed for transforming from three phase to two phase, or vice versa. The connections shown herewith include the ones most commonly used, as well as others which are given chiefly as matters of interest or as suggestions for possible emergency connections. For purpose of comparison, each connection has been arranged to transform 100 k.v.a. from three-phase, 2000 volts, to two-phase, 100 volts, and the current and voltage in each part of the winding are shown.

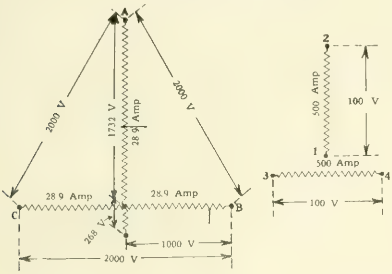


FIG. 1

The Scott connection, which is used in probably, more installations than all the others, is shown in Fig. 1. This requires two transformers, which are generally duplicates. They are similar to standard transformers except that the three-phase winding is provided with a tap at the middle and at the 86.6 percent point. Care must be taken to have the two halves of the three-phase winding of the main transformer closely linked magnetically to avoid excessive regulation on one phase.* If

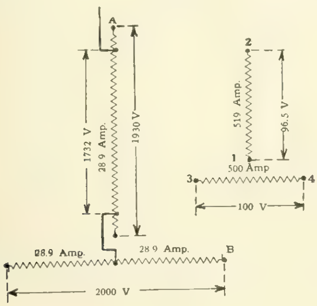


FIG. 2

the transformers are designed for this connection, this point is always taken care of by the manufacturer, but trouble may result if odd transformers are put together to make a three-phase, two-phase bank. The size transformer parts required in the example chosen is,—

$$\frac{2000 \times 28.9 + 100 \times 500}{2 \times 1000} = 53.9 \ k.v.a.$$

* See article by Mr. E. G. Reed in this issue of the JOURNAL

or for the bank $\frac{53.9 \times 2}{100} = 1.078$ times the k.v.a. transformed. In Fig. 2 is shown an approximation to the same scheme made by using for the main transformer a standard transformer with a middle tap, and for

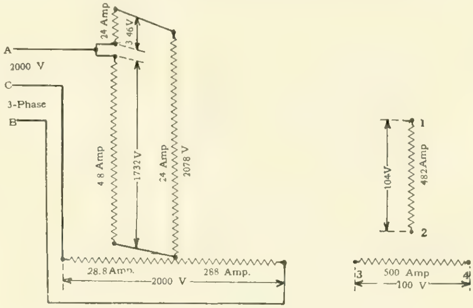


FIG. 3

the teaser a standard transformer having two 5 percent taps. This combination gives secondary voltages which are somewhat unbalanced, but it is sometimes useful in emergencies.

Another approximation is shown in Fig. 3. Three

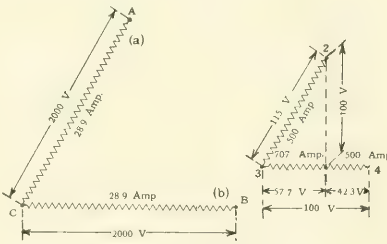


FIG. 4

standard transformers are used, one having a middle tap, for the main unit; one with or without taps for the teaser unit; and a small transformer having a 5 to 1 ratio for the auxiliary. The auxiliary is used as an

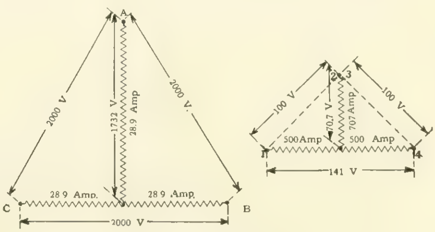


FIG. 5

autotransformer to raise the voltage on the teaser phase so as to make the two-phase voltage more nearly balanced. The parts required are,—

$$\text{Main } \frac{2000 \times 28.8 + 100 \times 500}{2 \times 1000} = 53.9 \ k.v.a.$$

$$\text{Teaser } \frac{2000 \times 24 + 104 \times 482}{2 \times 1000} = 49.1 \text{ k.v.a.}$$

$$\text{Auxiliary } \frac{1732 \times 4.8 + 24 \times 346}{2 \times 1000} = 8.35 \text{ k.v.a.}$$

This arrangement connects the low-voltage winding of the auxiliary transformer in the high-voltage circuit,

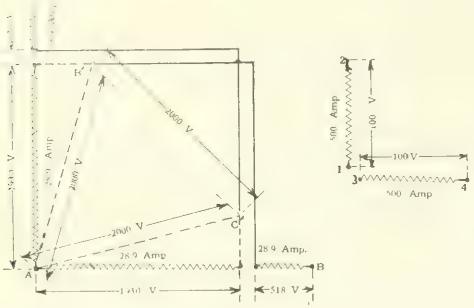


FIG. 6

and this imposes on the low voltage insulation greater stresses than it was designed to stand. For this reason it may be necessary to insulate the tank of the auxiliary transformer from ground. If this is done, it should be protected so that it will be impossible for anyone to touch it.

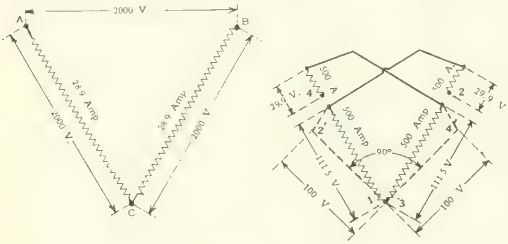


FIG. 7

The scheme shown in Fig. 4 may be useful under special conditions. It shows how transformers which were built for two-phase high to three-phase low may be connected for a three-phase high to a two-phase low. The parts required are,—

$$\text{Transformer with taps } \frac{2000 \times 28.9 + 57.7 \times 707 + 12.3 \times 500}{2 \times 1000} = 59.8 \text{ k.v.a.}$$

$$\text{Transformer without taps } \frac{2000 \times 28.9 + 115 \times 500}{2 \times 1000} = 57.7 \text{ k.v.a.}$$

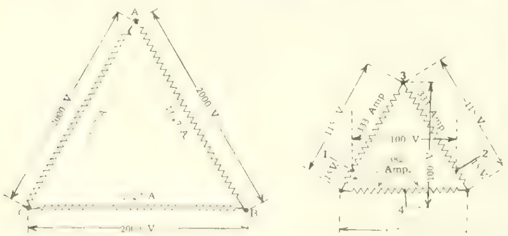


FIG. 8

Or if two transformers alike are used each will take,—

$$\frac{2000 \times 28.9 + 57.7 \times 707 + 57.7 \times 500}{2 \times 1000} = 63.6 \text{ k.v.a.}$$

If the transformers have a 20 to 1 ratio the two-phase voltage will be 86.6 instead of 100. This may be raised by using autotransformers, or if there are taps in the high-voltage winding they may be used to raise the two-phase voltage.

The connection given in Fig. 5 is used by at least one large generating company. It gives a three-wire,

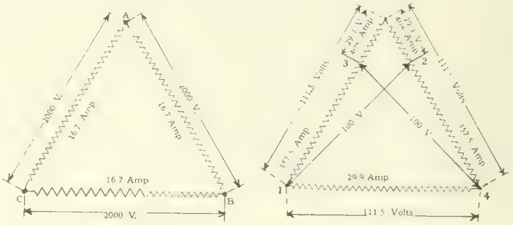


FIG. 9

two-phase system as shown. The parts required are,—

$$\text{Main } \frac{2000 \times 28.9 + 141 \times 500}{2 \times 1000} = 64.2 \text{ k.v.a.}$$

$$\text{Teaser } \frac{1732 \times 28.9 + 70.7 \times 707}{2 \times 1000} = 50 \text{ k.v.a.}$$

The connections shown in Figs. 6 and 7, while possible, are seldom used. The parts required are :—60.4 k.v.a. for each transformer in Fig. 6 and 64.3 k.v.a. for each in Fig. 7.

Fig. 8 shows the Taylor connection which is used occasionally. It requires three single-phase or one three-phase transformer with taps as shown. The parts required for the transformer having a middle tap are,—

$$\frac{115 \times 382 + 2000 \times 16.7}{2 \times 1000} = 38.7 \text{ k.v.a.}$$

and for the other two transformers are,—

$$\frac{15 \times 382 + 100 \times 333 + 2000 \times 16.7}{2 \times 1000} = 36.2 \text{ k.v.a.}$$

or a total for the bank of 111.1 k.v.a. If the transformers are interchangeable, a total capacity of 116.1 k.v.a. is required.

Fig. 9 is the Fortescue connection. It has taps located as shown, on a delta connection, so that the

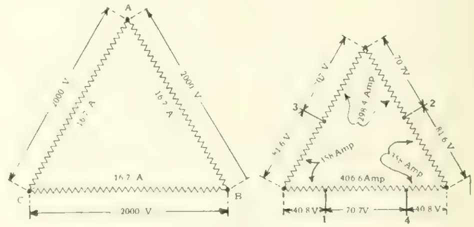


FIG. 10

voltage *1-2* is at right angles to the voltage *3-4*. The parts required for the transformer without taps are,—

$$\frac{111.5 \times 299 + 2000 \times 16.7}{2 \times 1000} = 33.4 \text{ k.v.a.}$$

and for the other two transformers,—

$$\frac{357.5 \times 81.6 + 408 \times 29.9 + 16.7 \times 2000}{2 \times 1000} = 37.4 \text{ k.v.a.}$$

Fig 10; the Arnold connection, is similar to the two foregoing except in the location of the taps. It

has the advantage that the two two-phase voltages are symmetrical with respect to a neutral point, and may therefore be connected to an interconnected two-phase

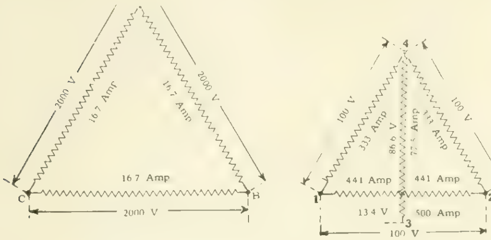


FIG. 11

system. The parts required for the two similar transformers are,—

$$\frac{2000 \times 16.7 + 81.6 \times 358 + 70.7 \times 298.4}{2 \times 1000} = 41.83 \text{ k.v.a.}$$

and for the third transformer,—

$$\frac{2000 \times 16.7 + 40.8 \times 358 \times 2 + 70.7 \times 406.6}{2 \times 1000} = 45.65 \text{ k.v.a.}$$

or a total of 129.3 k.v.a.

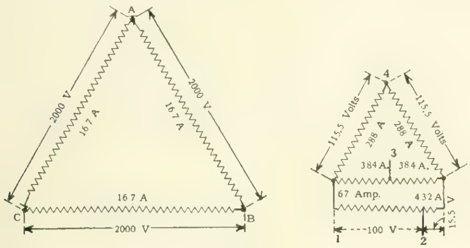


FIG. 12

Figs. 11 and 12 show ways of taking two-phase from a three-phase delta connection using autotransformers. The parts required for the transformer with the middle tap in Fig. 11 are,—

$$\frac{2000 \times 16.7 + 441 \times 100}{2 \times 1000} = 38.75 \text{ k.v.a.}$$

For the two similar transformers,—

$$\frac{2000 \times 16.7 + 333 \times 100}{2 \times 1000} = 33.3 \text{ k.v.a.}$$

And for the autotransformer,—

$$\frac{86.6 \times 77.5 + 13.4 \times 500}{2 \times 1000} = 6.7 \text{ k.v.a.}$$

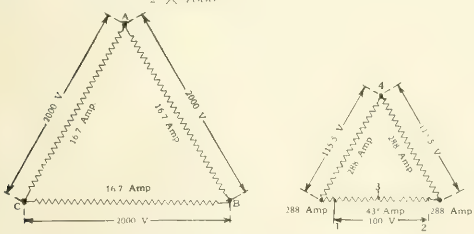


FIG. 13

Similarly in Fig. 12 the parts required for the transformer with a middle tap are,—

$$\frac{2000 \times 16.7 + 115.5 \times 384}{2 \times 1000} = 38.9 \text{ k.v.a.}$$

For the two similar transformers,—

$$\frac{2000 \times 16.7 + 115.5 \times 288}{2 \times 1000} = 33.3 \text{ k.v.a.}$$

and for the autotransformer,—

$$\frac{100 \times 67 + 15.5 \times 432}{2 \times 1000} = 6.7 \text{ k.v.a.}$$

Fig. 13 is similar to Fig. 12 except that taps are

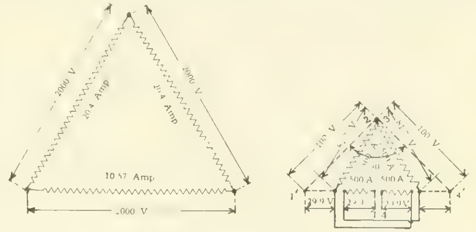


FIG. 14

put into one of the transformers to take the place of the autotransformer. The parts required for the tapped transformer are,—

$$\frac{2000 \times 16.7 + 100 \times 435 + 15.5 \times 288}{2 \times 1000} = 41.2 \text{ k.v.a.}$$

and for the other two transformers 33.3 k.v.a. as above.

Fig. 14 gives another arrangement of three transformers to give two-phase. One transformer has its

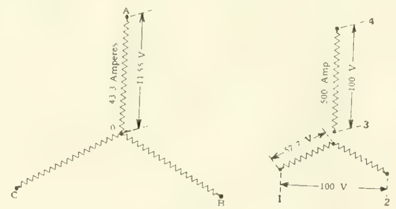


FIG. 15

secondary winding in two parts so connected to the other two transformers as to give a two-phase three-wire system. The parts required for the two duplicate transformers are,—

$$\frac{2000 \times 20.4 + 81.7 \times 500}{2 \times 1000} = 40.8 \text{ k.v.a.}$$

and for the third transformer,—

$$\frac{2000 \times 10.57 + 29.9 \times 500 \times 2}{2 \times 1000} = 25.05 \text{ k.v.a.}$$

Another method which has been suggested is shown in Fig. 15. The objection to this scheme is that for the

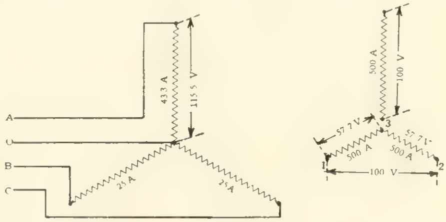


FIG. 16

phase *3-4* the primary *AO* is in series with the two other primaries *OB* and *OC*, which act as impedances in series with *AO* and consequently the regulation of

the phase *3-4* will be very poor. A modification of this method has been used with a three-phase system having a neutral wire connected to the generator. In this case the load on *3-4* is carried on one of the generator windings and the load on phase *1-2* is carried on the other two windings as shown in Fig. 16. The parts required for each of the two similar transformers are,—

$$\frac{1155 \times 25 + 57.7 \times 500}{2 \times 1000} = 28.9 \text{ k.v.a.}$$

TABLE I TOTAL K.V.A. OF TRANSFORMERS REQUIRED TO TRANSFORM 100 K.V.A. FROM 2000 VOLTS, THREE-PHASE TO 100 VOLTS, TWO-PHASE

Fig.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	16
Trans. 1	53.9	55	49.1	59.8	50	60.4	64.3	38.7	33.4	45.7	38.8	38.9	41.2	25.1	50
Trans. 2	53.9	53.9	53.9	57.7	64.2	60.4	64.3	36.2	37.4	41.8	33.3	33.3	33.3	40.8	28.9
Trans. 3	......	......	......	......	......	......	......	36.2	37.4	41.8	33.3	33.3	33.3	40.8	28.9
Autotransformer	......	......	8.4	......	......	......	......	......	......	......	6.7	6.7	......	......	......
Total	107.8	108.9	111.4	117.5	114.2	120.8	128.6	111.1	108.2	129.3	111.6	126.2	107.8	116.7	107.8

and for the third transformer,—

$$\frac{1155 \times 13.3 + 100 \times 500}{2 \times 1000} = 50 \text{ k.v.a.}$$

This gives an unbalanced load on the generator, but if there are several such banks on the system, they may be distributed among the three lines so as to balance the generator load approximately. A case in point is a company which had a four-wire, three-phase, 4000 volt system and some standard transformers of 10 to 1 and 9 to 1 ratio. The secondary windings of two 9 to 1

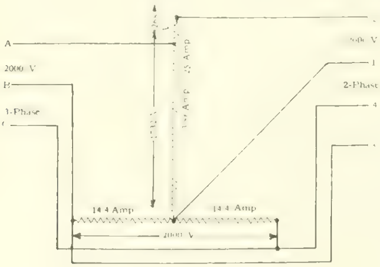


FIG. 17

transformers were connected in parallel giving an 18 to 1 ratio, and they were used as the two similar transformers in Fig. 16 giving,—

$$2300 \times \frac{1}{9 \times 2} \times \frac{1}{0.577} = 222 \text{ volts on secondary phase } 1\text{-}2$$

A 10 to 1 transformer was used as the third unit and gave $\frac{2300}{10} = 230$ volts on secondary phase *3-4*. This, while not a perfectly balanced two-phase system, enabled two-phase motors to be run without buying new transformers.

AUTOTRANSFORMERS

It is sometimes desirable to transform from three-phase to two-phase, or vice versa, without changing the voltage, or with a relatively small change in voltage. In this case autotransformers offer considerable econ-

TABLE II—TOTAL K.V.A. OF TRANSFORMER PARTS REQUIRED TO TRANSFORM 100 K.V.A. FROM THREE-PHASE TO TWO-PHASE BY AUTOTRANSFORMERS FOR VARIOUS VOLTAGE RATIOS

$$\text{Ratio} = \frac{\text{2-phase voltage}}{\text{3-phase voltage}}$$

Ratio	0.5	0.75	1.0	1.5	2.0
Teaser parts	21.15	6.6	6.65	21.15	28.4
Main parts	28.9	19.7	14.4	25.	31.6
Total	40.05	26.3	21.05	46.15	60.0

omy over two-winding transformers. Fig. 17 shows such a pair of autotransformers arranged to transform 100 k. v. a. from 2000 volts three-phase to 2000 volts two-phase. The parts required for the main unit, for a one to one voltage ratio are,—

$$\frac{2000 \times 14.4}{2 \times 1000} = 14.4 \text{ k.v.a.}$$

and for the teaser,— $\frac{1732 \times 3.8 + 268 \times 25}{2 \times 1000} = 6.65$ k.v.a.

Autotransformers show their maximum advantage for an 0.866 voltage ratio.

THE JOURNAL QUESTION BOX

OUR subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. The topics should be of general interest, information involving the specific design of individual pieces of apparatus is not supplied. Care should be used to include all data necessary for an intelligent answer.

A PERSONAL reply is mailed to each questioner enclosing a stamped, self addressed envelope as soon as the necessary information can be obtained. Anonymous questions cannot be considered. As each question is answered by an expert on the subject involved, and checked by at least two others, a reasonable length of time should be allowed before expecting an answer.

1711 — CARRYING CAPACITY OF IRON PIPES—Can you advise regarding current carrying capacities for both thirty and sixty cycles alternating current of standard extra heavy, and double extra heavy pipe, ¾ in., 1 in., and 1-¼ in. sizes? We want to use the above pipe sizes for high-tension bus work, 20 000, 40 000, 70 000 and 140 000 volt service. The voltage drop need not be considered, the determining factor being the heating.
L.E.B. (MICH.)

We have no record of curent carrying tests on wrought iron pipes using thirty cycle alternating curent, nor have we made any tests on the extra heavy and double extra heavy pipes. However from the test results with 60 cycles on the standard ¾ in., 1 in., and 1-¼ in sizes given in Table I a fair estimate can be made as to the small additional current allowable for the heavier pipes for a given temperature rise. The fact that the conductor is made of magnetic material and the tendency of the current to crowd to the surface (skin effect) indicates that the curent carrying capacity of the heavy pipes will be but little above the capacity of the standard sizes.
F.M.B.

TABLE I. TEMPERATURE RISE ON ALTERNATING CURRENT 60 CYCLES

	30 degrees C.	40 degrees C.
¾-in. Std. W. I. Pipe	120 Amps.	150 Amps.
1 -in. Std. W. I. Pipe	190 Amps.	235 Amps.
1¼-in. Std. W. I. Pipe	225 Amps.	280 Amps.

1712—REVERSAL OF EXCITER VOLTAGE—Two 500 kw, 2200 volt turbine driven alternators with direct-connected exciters are operating in parallel. The exciters are commutating-pole compound-wound with the usual equalizer connection. They are connected in parallel and are under Tirril regulator control. One exciter overcomes the other apparently and it becomes motorized. The generators drop their load but very soon pick it up again but with both exciters reversed. Is it possible for one exciter to reverse the other (where the usual equalizer connection is used) and why, after the alternators have dropped their load and picked it up again, are both exciters reversed?
E.M. (N.Y.)

With an exciter system in proper adjustment, it is practically impossible for a reversal of polarity to occur. If it does happen, the cause is likely to be found in some abnormal condition. Generally, such reversal results from a demagnetizing action of the exciter load current. When a surge, for instance, causes the regulator momentarily to diminish the exciter voltage to a low value, the exciter load current is not reduced much on account of the inductance of the alternator field, and the demagnetizing effect may overpower the weak shunt field, thereby reversing the polarity. This demagnetizing action would be present in an exciter having its brushes shifted forward and having little or no series field, or a reversed series. In a commutating pole machine, where the brushes are set on the no-load neutral, the armature would not produce a demagnetizing effect, but this effect could come from a reversed series winding. The motoring of one exciter by the other would not be expected to cause polarity reversal. If it is the cause, some unusual combination of circumstances must exist. Stable parallel operation requires that each machine have a tendency to shirk its load, that is, an excess load on one exciter should be followed by a reduction in the voltage of that exciter with a consequent tendency to drop its load. A relatively high internal drop, a drop in speed with increasing load, a bucking series field (connected inside the equalizer), and a forward brush lead, all add to this tendency to shirk. This tendency is lessened or removed if an unbalancing of the load between the two machines is followed by an appreciable magnetizing effect in the one taking more than its share of the load, and the reverse in the other. This is not liable to occur if the equalizer resistance is very low, and there is a reasonable degree of saturation in the magnetic circuit. In the present case, these stabilizing influences would be weak, or absent, so a comparatively slight disturbance may cause considerable inequality in the load division, and may result in a circulation of current between the two machines. The parallel operation could be made much more reliable by the use of a light bucking series winding, connected inside of the equalizer, say between the equalizer and commutating-pole winding—or by reversing the present series winding and doing away with the equalizer. This bucking effect should be quite small, or else polarity reversal may occur in the way suggested above; and it must be made certain that the shunt field winding has sufficient capacity to carry the increased ampere-turns required from it. With more complete data at hand, probably a more satisfactory explanation of the phenomenon could be offered.
F.L.M.

1713—CARRYING CAPACITY OF COPPER WIRES—In a printed table, wires or certain sizes cary a certain amount of current. For instance a 0000 wire carries 325 amperes. At what voltage basis is this figured? What amperes would the 0000 wire carry at 110, 220, 550, and 22000 volts? What voltage does the Board of Fire Underwriters' base the safe carrying capacity of wires on as listed in their regulations. If this same wire were used for several different voltages, how would the carrying capacity in amperes be figured? Please give me a rule for finding the size of the wire required to carry a certain current with so many volts drop at a certain voltage?
F.H. (W.VA.)

There is no definite carrying capacity of a copper wire, as a wire will carry any current that is forced through it unless it melts first. The usual practical limit of carrying capacity is the current at which the temperature will rise sufficiently to damage the surrounding substances. This temperature will obviously depend upon the suroundings; it can be very much higher for mica insulation, for instance, than for cotton insulation. Also the current which is required to raise the temperature a certain number of degrees depends on the ventilation. For instance, wire strung on a pole with the air free to circulate all around it will carry a much higher current per degree temperature rise than will a wire enclosed in the wall of a house where there is no chance for ventilation. The carrying capacity of wires as listed by the Fire Underwriters is that current which the Underwriters consider can be carried safely, that is without any fire risk, when the wires are completely enclosed in the walls of the house so that there is no chance of ventilation. From the above it is evident that the carrying capacity is dependent only on the heating effect, and hence is dependent only on the current which passes through the wire, and is entirely independent of the voltage between the wires. Hence the Underwriters tables are independent of the voltage. For this reason, it is not always safe to use the smallest wire which is allowed by the Underwriters, as this wire may be large enough to carry the current without heating but at the same time may cause a sufficient voltage drop to give poor regulation; that is, the wire may absorb so much of the voltage that the lamps will burn dimly or the motors operate at slow speed. A well known rule for determining the size of wire with respect to voltage drop for direct current is:—

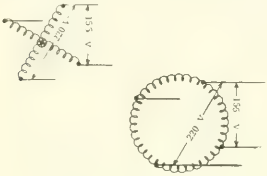
Volts drop = 10.7 × *amperes* × *length of circuit in feet divided by circular mils.*

This rule is based on copper wire at 75 degrees and of 98 percent conductivity. The length of the wire is twice the length of the circuit. For short runs and low current values, this rule is satisfactory for single-phase alternating-current. For longer lines, the alternating current calculations are more complicated. A chart for the rapid estimating of the voltage drop in alternating-current lines is given in an article by Mr. H. B. Dwight in the JOURNAL for July 1915, p. 306.
C.R.R.

1714 — VOLTAGE BETWEEN PHASES — Please explain why I am able to get approximately 110 volts between phase *A* and phase *B*, no matter what lines

are used on a certain two-phase four-wire 220 volt system? I have this same result twice, with a 220 volt test lamp. A.H.K. (CAL.)

The existence of the voltages mentioned may be due entirely to high resistance grounds on the distribution lines, to leakage between phases, or the generator winding may be such that there is electrical connection between phases. If the voltages are due to such grounds, they might have any value, but it is not probable that the voltages



FIGS. 1714(a) and (b)

between each pair of leads will be the same as stated; but, if the voltages were measured only by the test lamp, the lamp might appear to be heated to about the same color even with fairly wide differences in voltage. If the voltages are due to electrical connection between phases in the generator winding, they would be equal and would be 155 volts across each phase. The connection between phases might be made at the neutral, as in Fig. (a) or the winding might be similar to a two-circuit direct-current winding, as in Fig. (b). The voltages should be measured by a voltmeter to determine which of these reasons is the right one. If the lamp burns with about the same color when connected between each pair of leads of different phases when the feeder switches are all open (all load being disconnected from the generator), the voltages are probably due to the type of armature winding. F.D.N.

1715—RE-1662—In No. 1662 (Nov. '18) you say that the number of rotor bars follows the number of stator slots. What would be the effect if the bars are greater or less in number than the slots? J.H.B. (WYO.)

The answer to 1662 states only that the number of rotor bars (or slots) follows from the number of stator slots. The number of rotor slots should be greater or less than the number of stator slots by at least 15 percent to insure against too great a variation in magnetic reluctance, which results in a tendency toward dead or locking points. On motors with a large number of poles it is better to have the number of rotor slots greater than the stator slots, as the rotor slot and zig-zag leakage reactances, which are a large proportion of the total leakage reactance, will be less and the losses due to pulsations of flux which will be increased are of little consequence. On the other hand for motors with a small number of poles, say eight poles and lower, it is better to have the number of rotor slots less than the stator slots, for the rotor slot and zig-zag leakage reactances which would be increased are a small proportion of the total leakage reactance, and the pulsation losses above mentioned would be greatly decreased, and these are of considerable consequence on the high-speed motors. B.B.R.

1716—20 HP ROTOR IN A 37 HP STATOR—What service can be expected from a motor comprised of a 37 hp, 1200 r.p.m. stator and a 20 hp, 900 r.p.m. squirrel-cage rotor. Their parts are interchangeable mechanically. J.H.B. (WYO.)

In an eight-pole rotor, the end ring is in effect in eight parallels; while in a six-pole motor the ring is in six parallels, which causes the same ring to have 80 percent more resistance when used with a six-pole primary than when used with an eight-pole primary. The resistance of the bars is not affected by the different primaries and since in a six or eight-pole motor the bar resistance is a large part of the total resistance, the large increase in the ring resistance does not make a corresponding increase in the total resistance. This increase in the secondary resistance will give an increased rotor loss and rotor heating but not sufficient to injure the motor. This increase in resistance will also give greater slip, greater starting torque and slightly lower efficiency. The above is on the assumption that the 900 r.p.m., eight-pole rotor is not a special high-slip rotor but a rotor for normal slip, in which case it should be possible to obtain the full rating from the 37 hp primary with this squirrel-cage rotor. B.B.R.

1717—VENTILATION OF ALTERNATOR—Assume the case of a 5000 k.v.a., 2300 volt alternator having both intake and discharge air ducts. What rise in temperature of the cooling air may we expect, the required volume of air being furnished the machine at full load? What would be a fair value to assume for the pressure drop through a cheese cloth screen placed in the intake duct? Would it not be more correct in approximating the cooling air required to take it as cubic feet per minute per ampere rather than per kilowatt? M.J.I. (D.C.)

A temperature rise of 25 to 30 degrees C may be expected in the cooling air of a turbogenerator. The pressure drop through a cheese cloth screen is a variable quantity, depending on the fineness of the mesh and the amount of dirt suspended in the screen. Tests at a velocity of 50 feet per minute have shown that drops are obtained of 0.2 inches of water column when the screen is clean, and 1.5 inches when dirty. The quantity of cooling air cannot be based on ampere rating, as the copper loss in a turbogenerator is small compared with the iron loss and friction and windage, which are practically constant for all loads. For this reason, the cubic feet of air should be based on the total loss in the generator. A safe figure to allow is approximately 80 cubic feet per kilowatt loss. A turbogenerator maximum rated at 5000 k.v.a., will require approximately 24000 cubic feet of air per minute. S.L.H.

1718—SHORT-CIRCUITED WOUND ROTOR—What service can be expected from a wound rotor motor with short-circuited rings and a compensator for starting? Is this installation liable to show dead spots when starting? Will short-circuiting each and every rotor bar of a wound rotor give it the same characteristics as a squirrel-cage rotor? J.H.B. (WYO.)

In case the wound rotor has a high-resistance winding it will give a fairly good starting torque with the rings short-circuited. It is however, liable to show locking points and may give trouble if used to start a load requiring even a moderate torque to start it. Short-circuiting every rotor bar with a ring will give a rotor having characteristics similar to those of a squirrel-cage rotor. Just what the actual performance of the motor will be, will depend on the total resistance of the rotor circuit. B.B.R.

1719—40 VS. 60 CYCLES—Why is the efficiency or power-factor higher on a 30 cycle line than on a 60 cycle line and is there any other advantage of a 30 cycle system? Does a 30 cycle motor have a higher power-factor than a 60 cycle? In changing over 60 cycle motors to 30 what loss is there? Can the same current transformers and ammeters be used on 30 and 60 cycle circuits? We are changing over from our present 60 cycle system to 30 cycles. G.L.MCL. (QUEBEC)

For the same speed and output the efficiency of 30 and 60 cycle motors is about the same, but the power-factor is higher in the case of 30 cycles due to the fact that the number of poles in the 30 cycle motors is one half that in the 60 cycle motors. This higher power-factor gives a lower full-load current which, together with the lower reactance of the 30 cycle transmission system, gives a lower line drop for the same horse-power load. An objection to the use of a 30 cycle instead of a 60 cycle system for supplying a motor load is that 30 cycle motors can be obtained commercially for speeds of only 1750, 850 and 585 r.p.m. while 60 cycle motors can be obtained for speeds of 3450, 1750, 1160, 860, 700, 585 and 500 r.p.m. Motors built for 60 cycle operation in most cases can be changed for 30 cycles only by maintaining the same number of poles, which reduces the speed and horse-power output to one half. If the voltage of the 30 cycle system is the same as for 60 cycles the motors can usually be changed for the same number of poles by reconnecting the primary winding with one half the number of parallel circuits. If the 30 cycle voltage is reduced to one half the value at 60 cycles no change is necessary in the motors. For either of the above changes for 30 cycles with half the speed and output, the power-factor will be the same as at 60 cycles but the efficiency will be from five to eight percent lower. In some cases it is possible to change 60 cycle motors for 30 cycles and obtain the same speed and output by rewinding the motors for half the number of poles, but it is advisable to consult the motor manufacturer before attempting such changes. Most commercial current transformers and meters can be used interchangeably on 30 and 60 cycles. O.S.

1720—DELTA VS STAR CONNECTION—I have a five hp, four-pole, 220 volt induction motor with 48 coils connected parallel star. Each coil is wound with 18 turns of No. 15 D. C. C. wire. Another four-pole, 220 volt motor has 48 coils connected series delta. The coils in this motor are wound with 16 turns of No. 15 wire. From previous articles and

answers I can see why the series delta motor has two turns per coil less than the parallel star motor, but my question is, what is the advantage of or the reason why one motor is connected series delta and the other one parallel star? The name plate ratings of both motors were alike as to voltage phase, speed and frequency but the current in amperes differed by one or two tenths of an ampere.
H.P.W. (PA.)

In general, designers use the star or delta connection depending upon which one of the two gives not only an integral number of conductors per coil, but also that number of conductors that will utilize the available sizes of conductors to the best advantage in the slot space. It is desirable to arrange the windings of motors so that they can be connected for voltages of 440, 220 and 110 (in small motors) without changing the coils, which means that for a four pole motor the connections must be in series for 440, parallel for 220 and double parallel for 110 volts. It is seen then that the motor connected series delta on 220 volts cannot be reconnected for 440 volts without materially changing its performance and that to arrange it for this reconnection would require either a parallel delta connection with 32 turns per coil or a parallel star connection with 18 turns per coil. In motors such as five horsepower and smaller, where the number of turns in the coils are large it is desirable to keep the number of turns as small as possible and the size of the wire as large as possible to strengthen the coil mechanically, decrease the cost of winding the coil, and reduce to a minimum the sum total of insulation on the wires in the coil. Therefore the star connection instead of the delta would be the more desirable one to use in this case and is the one generally used on the smaller motors.
O.S.

1721 — Regenerative Braking in a Coal Mine—We have twelve 37 hp, three-phase wound-rotor motors operating on a very poorly regulated system. On account of small copper the voltage, when several motors are running, is reduced 50 percent. The motors are used to hoist coal out of a mine and the distance traveled up hill with a load is equal to the distance traveled down without a load. The relative weight of a load and car to an empty car is 5 to 2. Will lowering the empty cars with the motor (regenerative braking) improve the voltage on the line in such a way that the additional power will be available for the other equipment? Please give me an idea of the speed of the car going down hill on different points of the controller. Will the motor pull out when regenerating at about the same rope strain as when used to hoist. What is the power-factor when regenerating?
J.H.B. (WYO.)

The motors can be used for regenerative braking in the manner suggested, but we do not anticipate any marked improvement in voltage conditions in this case because of the small capacity and the low ratio of lowered load to hoisted load. If it is assumed that the average motor load when hoisting is 35 hp, then on lowering the empty car, the rope pull available for driving the motor as a generator would be equivalent to approximately seven hp, assuming 50 percent efficiency for the hoist equipment. And further assuming that at this load the generator efficiency would be approximately 60 percent, it is seen that the electrical output is only about three kw. This means that if at any time six machines were operating as motors and six operating as generators the total electrical output would be 18 to 20 kw, while the total electrical input to the six motors would probably be ten times this amount. For equal rope pulls the power-factor as a generator would be a few percent less than as a motor. The maximum rope pull obtainable when driving the generator would be somewhat greater than obtainable when operating as a motor due to the losses in the machine. It should be noted that if lowering is done by this method it is necessary to plug the motor or use the mechanical brakes to make a stop, as inserting resistance in the secondary of the generator decreases the torque and allows the speed to increase.
T.W.

1722—Reversal of Generator Voltage —In pulling out the main switch when a direct-current generator is loaded it sometimes reverses the polarity. Why is this? E.M. (N.Y.)

If the generator is connected properly, reversed polarity will not result from the simple cause mentioned above. Certain combinations are possible, and are sometimes met with, which permit such action to take place. In the present case there is not enough information available to allow any explanation. A condition, for example, under which reversal of polarity may occur, is this: A generator feeding a highly inductive circuit is disconnected inside the shunt field connections, thus leaving the shunt field winding connected to the load circuit. If the stored energy in the load circuit is greater than that in the shunt field, the former will discharge through the shunt winding; and the reverse current in the latter, unless very slight, will reverse the remanent magnetism in the machine.
F.L.M.

1723—Telephone Interference—I have a three-phase, 60 cycle, 22 000 volt transmission line, 42 miles long, carrying about 400 kw with the wires strung on poles on our own right of way. There is a telephone line with two wire metallic circuit on the same poles and on account of the induction, the telephone is very noisy, making the use of the telephone impossible when the power is on. The line passes over the mountains at an altitude of not over 3000 ft. through normally dry air. The telephone line has been transposed every 1500 ft. but the power line is transposed but once. In order to lessen the induction should the telephone line be transposed oftener? What distance between transpositions? How should the transpositions be arranged? Should the main power line be transposed also? If so, how often? In the towns the arc lamp circuits seem to cause induction in local telephone circuits; why is this? The arcs are direct-current series metallic flame type. Induction is not noticed except when the arcs are on. How can this type of induction be eliminated?
C.E.A. (SANTO DOMINGO)

(a) The 22 000 volt power line should be transposed as well as the telephone circuit which runs on the same poles. (b) Three or four complete transpositions or "barrels" should suffice if the location of the power wires with respect to the telephone wires is uniform. By a "barrel" is meant an arrangement of a section of the power circuit within which each conductor occupies each of the conductor positions for equal distances. For instance, for a 12 mile barrel, conductor *A* would occupv pin *1* for four miles; pin *2* for the next four miles; and pin *3* for the third four miles. Conductor *B* would occupy pin *2* for the first four miles, pin *3* for the second and pin *1* for the third. Conductor *C* would occupy pin *3* for the first four miles, pin *1* for the second and pin *2* for the third. The telephone line should be transposed with respect to the transpositions of the power line, so that both telephone conductors will occupy a given position for equal total distances for each configuration of the power circuit. (c) By carefully providing transpositions in the lines in accordance with the above scheme, and at the same time, seeing that the telephone conductors are well insulated and balanced as regards insulation resistance, the interference will probably be eliminated. However, there may be induction, due to an unbalanced condition in the power circuit, such as would be the case if one conductor were grounded or poorly insulated from ground. If the neutral is grounded at more than one point there may be present unbalanced loads from the conductors to neutral, or an unbalanced third harmonic may exist. The elimination of the third harmonic by means of star-delta connected transformers is possible. (d) Current in the arc lamp circuit is probably not a smooth direct current, on account of the use of rectfiers for obtaining the current. The interference from this current, however, should not be serious if the telephone line is well transposed and well maintained and is located at a distance from the lighting circuit which can be considered safe from the standpoint of physical hazard. Of course, if the telephone line is a grounded circuit, there will be interference. Grounded telephone circuits are now considered obsolete, largely on account of their liability to inductive interference troubles.
A.W.C.

CORRECTIONS

In the subtitle to Fig. 14, p. 468, of Mr. Mahoney's article in the Journal for Nov. '18, the words "all synchronous" and "connected" should be omitted, as this chart is based on a fixed reactance, and does not include the change of reactance with time, which takes place in synchronous apparatus as shown in Figs. 6 and 7. It is also based on constant voltage, which presupposes sufficient generating capacity to maintain this condition approximately.

In the Journal for Feb. '19, the title to Fig. 5, page 48, should read "TEMPERATURE CURVES AT FULL LOAD AND 1.5 LOAD WITHOUT BLOWER." The title to Fig. 9, page 50, should read "DIRECT-CURRENT SHORT-CIRCUIT TEST AT 20 TIMES FULL LOAD." In the first equation on page 65, "10" should read "10^{-7}".

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country. The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

MARCH 1919

Railway Motor Testing--III

In overhauling or repairing railway motor frames or fields, it is advisable to test certain detail parts before they are placed in the frames, to insure against unnecessary work during the rebuilding of motor. A very good precaution is to paint the inside of the motor frame thoroughly with a heavy asphaltum paint, before putting the field coils in place, taking care not to get any paint on the pole seat, which would tend to weaken the magnetic field.

BRUSHHOLDERS

Grounds—Brushholders of the insulated pin type should be given a test for grounds with the apparatus shown in Fig. 1

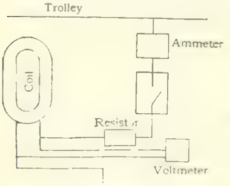


FIG. 16—BAR TO BAR SET

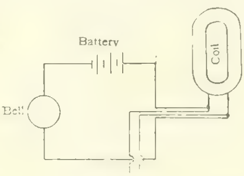


FIG. 17—TELEPHONE SET

or 4 (R. O. D. January, 1919) in a manner similar to that described for commutators, (R. O. D. February, 1919), placing one lead on the brushholder and the other on the brass support.

MAIN OR COMMUTATING-POLE FIELD COILS

COIL TESTING OUTFIT (Fig. 3)

Short-Circuits—Place the coil on either one of the outer legs of the coil testing outfit (Fig. 3), with the yoke removed. If the wattmeter needle deflects with the exciting coil switch closed, this indicates that some of the turns are short-circuited. In using this testing outfit, the wattmeter can be replaced by a telephone receiver. Then, if the coil is O. K., there will be a medium buzzing sound heard in the receiver, but if it is short-circuited, the sound will be much louder.

Open-Circuits—To test for an open circuit, place the coil on either one of the outer legs of the coil testing outfit with the yoke removed, and short-circuit the leads of the coil to be tested. No increase in the deflection of the wattmeter needle indicates that the coil is open circuited.

If the telephone receiver is used to replace the wattmeter in making these tests, with the coil leads disconnected, a medium sound is heard in the telephone receiver. If the sound is not changed by short-circuiting the coil leads, this is an indication that the coil is open circuited.

BAR TO BAR TESTING SET (Fig. 7)

Resistance Measurements—By means of this apparatus, connected as shown in Fig. 16, resistance measurements of a repaired or an old coil are taken. These can be compared with the correct resistance values obtained from the manufacturer of the coils, or from measurements of the resistance of a coil that is known to be O. K.

Indirect Method A—With this outfit, take a reading of volts and amperes (values to be kept within range of meters used, by varying the resistance of circuit) and by dividing the voltmeter reading by the ammeter reading, the resistance of the coil under test will be found. This relation is obtained from Ohm's Law, from which the resistance equals the volts divided by the amperes. These readings should be taken in a room where the temperatures are approximately 25 degrees C. or 75 to 80 degrees F.

Direct Method B—Probably a simpler method is to have a standard coil which is known to be O. K. in series with the coil being tested, and take two sets of voltage readings, one on the standard coil, the other on the test coil, holding the amperes the same while taking both sets of readings.

Short-Circuits—If the resistance values figured (method *A*) or if the voltmeter readings (method *B*) are low (ten percent or more) on the coil being tested, a short-circuit is indicated.

Open Circuits—If the resistance values figured (method *A*) or if the voltmeter readings (method *B*) are high (ten percent or more) on the coil being tested, a poorly soldered connection or an open circuit is indicated.

TELEPHONE RECEIVER SET (Fig. 5)

Using this apparatus connected as shown in Fig. 17, field coils can be tested by placing the terminals from the battery circuit and the terminals from the telephone receiver to the test coil leads, and noting the intensity of the sound in the telephone receiver. This method is not very sensitive in locating partial short-circuits.

Open Circuit—In testing with this outfit for open circuit, a loud click will be heard when the circuit is closed, rather than a sustained loud buzzing sound.

Short-Circuits—A medium sound in the receiver indicates that the coil is O. K., while a weaker sound indicates that the coil is short-circuited.

LIGHTING-OUT LINE (Fig. 4)

Open Circuits—If the lamps do not light up when the terminals of this outfit are applied to the leads of the field coil, the coil is open circuited.

ALTERNATING-CURRENT TESTING CIRCUIT

By means of the same apparatus as shown in Fig. 9, connected to 110 volt alternating-current circuit Fig. 18, coils can be tested for open and short-circuits. In using this apparatus, it is necessary to keep the current values in the coils down to approximately 40 to 50 amperes, so as not to overheat the windings of a normal coil.

Short-Circuits—If, after the switch has been closed for two or three minutes, excessive heating of certain parts of the coil is noted, some of the turns of the coil are probably short-circuited. In making this test, it is necessary that a closed iron magnetic circuit (preferably laminated) pass through the center of the coil and surround one side of the coil.

Open Circuits—If, when the switch is closed and then opened, no spark is drawn, the coil is open circuited.

NEW CENTURY TESTER (Fig. 6)

With this apparatus arranged as in Fig. 6, all of the above tests can be made on field coils, which give indications somewhat similar to those obtained by the use of the telephone receiver set.

The pointer is set to the standard reading given for the type of coil being tested, and if the sound continues without change when the switch lever closes the circuit on the two

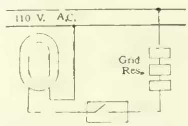


FIG. 18—A. C. TEST CIRCUIT

contact buttons, the coil is O. K. If the sound should be louder on one side of the switch than on the other side, the field coil is weak. In this case, push the pointer along the scale until the two sounds again become continuous. This second adjustment shows how badly the coil is affected.

COMPLETED FIELDS

Grounds—After the coils and brushholders are placed in the frame, and bolted down tight in place and all connections made, repeat the ground test with the apparatus in Fig. 1 or 4 as previously described.

Short-Circuits—The individual coils can be tested for short-circuits, using any of the above methods as outlined. It is advisable to make this test before the connections are taped.

Open Circuits—Test the coils and wiring-around-frame for open circuits with a lighting-out line as previously described.

Polarity Tests are to be made with apparatus connected as shown in Fig. 9. Current is passed through all of the coils connected in series, and by means of a compass needle, held to the same end of each coil, the polarity is checked by noting which end of the compass needle is attracted by this coil. Adjacent coils should attract opposite ends of the compass needle. For fuller details of this method, see R. O. D. December, 1916.

THE ELECTRIC JOURNAL

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The New South Philadelphia Works

More than usual interest attaches to the very complete article on the new South Philadelphia Works by Vice-president H. T. Herr, with supplementary descriptions by Oscar Otto, general superintendent of the works, and by Graham Bright, appearing elsewhere in this issue of the JOURNAL. Many of us have not known that the steadily increasing demand for Westinghouse products, under the broad constructive policy of the present management, has resulted in an expansion of the facilities of the parent and its subsidiary and controlled companies, until there are now 21 separate and distinct factories or sets of factories, distributed through eight States and employing in the neighborhood of 55 000 people.

When the indications of further continued growth resulted in a decision again to provide additional facilities, Philadelphia was selected, after a careful comparison of the advantages offered by different sections of the country. The importance attached to the enterprise by the management is indicated by Mr. Herr's statement that the total land occupied by the East Pittsburgh factories is 53 acres, whereas the South Philadelphia purchase comprises 500 acres.

The lay-out of the buildings already erected and the plans for their future extension are very clearly shown in Mr. Herr's article but his modesty has prevented him from repeating the encomiums almost universally forthcoming, from the many visitors who have inspected this development, for many of the features for which he is responsible. With two important railway systems serving the site, one on either side and each with an adequate yard, the facilities for getting raw material into the plant and finished products out of it are almost ideal, while the grouping of the buildings permits production with a minimum handling of material and that always in one direction. This statement applies to future extensions as well as to the present development.

Started as a peace-time enterprise necessary for the Company's expanding requirements, the building of the South Philadelphia factories could hardly have been better timed as a war measure. Long before they were completed their entire output for the period of the war was purchased by the Government for the equipment of vessels. At a time when the public funds were being appropriated with a lavish hand and production facilities of all kinds were being created with the utmost possible speed, in many cases with by no means the care and study that would be considered essential in peace times, the Westinghouse Company, without one penny of help from the Government, suddenly appeared with an entirely new and absolutely unhampered plant, of ample proportions, designed and built in the light of the best modern factory practice. It cannot fail to be a source of great satisfaction to the directors and officers of the Westinghouse Company that they were able to afford such substantial assistance to the Government's ship-building program.

A look at the finished plant itself discloses none of the many incidents of construction under abnormal conditions, many of which were trying. From the time when the president assigned to the writer the duty of contracting for and supervising the building of these factories until they were turned over to the production forces, the unexpected continued to happen. The Hog Island shipyard was started two and a half miles away. They wanted 28 000 men to build it. They choked up all the railroads with inbound freight and every passenger transportation agency with their employees travelling to and from work, because there was no near-by residential district. The Eddystone plant on the other side of us; The Sun Ship Building Company and the Chester Ship Building Company, all fairly near, made these conditions worse. Labor conditions, which were bad all over the country, became particularly acute here. We built a trolley loop on our land so that the single-end cars of the Philadelphia Rapid Transit Company, constituting 90 percent of their rolling stock, could be turned there, and a special route was established between Philadelphia and our loop. The Philadelphia & Reading Railroad double tracked their line through our property and were finally induced to run workmen's trains between our yard and Philadelphia morning and evening over a division previously used for freight only. This eased up the traffic situation and relieved the labor tension.

We had made our material contracts in good season but making contracts was one thing and getting deliveries under them quite another. What with priority certificates and freight embargoes, it was only by eternal vigilance that the succession of vexatious delays which did occur was prevented from becoming disastrous Credit is due to the systematic persistance of Westinghouse, Church, Kerr & Company for the efficient way they dealt with those difficulties. Starting with the tide levels in the Delaware River as a base and bearing in mind that wharves for sea-going craft might some day be built there, it was desirable that the property be so graded as to permit easy rail connection between these wharves and our factories as well as with the two railroad freight yards. The Philadelphia &

Reading track profile showed a summit opposite our land, the peak of which was some six feet too high to fit in with this plan. After extended negotiation the Railroad agreed to take out this hump and put their level where we wanted it. At the same time, by an exchange of realty, they rectified a curve and our enclosure was enlarged, thereby furnishing much needed space for yard tracks. An important through roadway, the "Island Road", divided our property and effectually blocked proceedings until, by a suitable Court decree, the relocation of this highway was legalized. Incidental to this work was the removal of a trolley line and the acquisition of the township school.

Another unexpected problem was the mosquito pest. This was so serious that at certain hours of the evening—during the summer of 1917—the colored laborers on night shift could only work with gunny sacks over their heads. It became evident that the pest might jeopardize our entire undertaking so the matter was vigorously attacked, with the ultimate result that there were combined the interests of the State, of the City of Philadelphia, of the League Island Navy Yard, of the United States Army owning an extensive rifle range near by and of the American International Shipbuilding Corporation. A fund of over $300 000 was raised and expended under the direction of the State Health Commissioner by experts skilled in the art. A system of ditches and laterals was built and two pumping stations installed. The water level of the swamp lands was lowered, stagnant pools eliminated and mosquito breeding prevented. This system, in addition to suitable oil treatment, was put into operation in 1918 and, although not started early enough in the season to have a complete test, resulted in such a mitigation of the pest as to warrant us in expecting early and complete success.

The co-operation of Westinghouse, Church, Kerr & Company in developing the details of the general designs provided for them and in pushing the actual construction of the work, after it had been started was most satisfactory. Under the general direction of vice-president J. C. Boyd and with the advice of their general engineering force, the work was handled by Mr. H. A. Brinkerhoff, managing engineer; Mr. F. E. Caldwell, engineer-in-charge, and Mr. F. H. McGraw, superintendent. Mr. R. B. Mildon, assistant to the vice-president, was detailed to assist the writer in his work in connection with the construction of the factories and of the town. To his unflagging energy, constant application and comprehensive grasp of the situation, is due—in a large measure—the successful results which have been obtained.

A further word regarding the housing development briefly touched upon at the close of Mr. Herr's paper may be of interest. Anticipating a possible future need for workmen's dwellings and considerably in advance of the actual demand, an investigation of the neighborhood possibilities was made and 90 acres of the company's tract, located across the Reading Railroad and immediately north of the factory was selected as the most promising site. This tract is not in any village. Mr. C. W. Brazer, town planning architect, of New York and Chester, was retained by the writer and made a study of all housing developments in the Philadelphia district and of some elsewhere, after which he prepared and submitted a plan for a complete town to contain when finished 1182 dwellings, as well as stores, churches, schools and an athletic field, with an estimated population, when completed and fully occupied, of 6329 people, men, women and children. With this plan in hand when it was suddenly decided to build, we simply selected a section of the proposed town site 22 acres in extent and proceeded at once with the development. There is room for 100 more houses, 300 in all on the same tract without crowding, when the demand calls for them.

The housing development is owned by the South Philadelphia Company, a separate corporation newly-created for that purpose. The town site is ideally located with respect to the factory. The houses are unusually well designed and constructed, and it is a satisfaction to record universally favorable comments by the tenants. With the expansion of our factories and of industry in the Delaware River Valley, the future borough of South Philadelphia should develop into a civic center of no mean importance.

Calvert Townley.

Storage Batteries in Automobile Service

The electric storage battery has been widely employed for storing energy when an excess is available and restoring it in dynamic form at other periods when the demand exceeds the supply. In some fields it has proved more successful than in others and the conditions of economic usefulness for these various applications were well recognized and standarized at the time when the manufacturers of motor cars began to realize the possibilities of electricity as applied to gasoline automobiles. At first this use was confined to lighting; then came the so-called "self-starter" or electric cranking device, and then the systems of ignition employing batteries instead of magnetos, all requiring storage batteries. Under the stimulus of the rapidly increasing demand for passenger cars and commercial vehicles, and the extension of the uses of electricity on automobiles, the storage battery industry took a new lease on life. Its expansion was phenomenal. It is probable that the total capacity of storage batteries annually applied to motor cars now exceeds many fold that used in any other field.

As must always be true where there is sudden and great popularity involving a process, a material or a device, there are good sound reasons in physical fact why the storage battery became immediately so generally used in the automotive field. The first of these is that the characteristics of the storage battery fit in admirably to complement the internal combustion

engine, which is not self-starting. To start it requires the application of a comparatively large amount of mechanical energy for a relatively short period, after which it becomes capable of doing not only its own work but also repaying the energy it borrowed to get under way. The electric storage battery, in connection with a starting motor and a small charging generator geared to the main shaft of the gasoline motor, exactly meets the condition of furnishing the heavy starting torque required to give the engine its initial start and gradually replenishing itself during the time when the engine is running.

The second reason for the popularity of storage batteries on automobiles is the adaptability of the electric system to wide variations in operating conditions involving speed, temperature, proportion of idle time to operating time, number of stops and many other variables. Consideration of Mr. Oetting's article in this issue of the JOURNAL makes it evident that the same starting equipment operated frequently at night by a doctor in Duluth in the dead of winter, and on the other hand operated by a racing driver between San Francisco and Los Angeles on a hot summer day might naturally be expected to perform somewhat differently, and yet such is the adaptability and the flexibility of the entire electric system that not one but many builders of motor cars can take care of just such widely varying requirements.

Two of the writer's feminine friends, who drive their own cars, were recently comparing notes. One remarked "I don't like to drive very well in cold weather. Sometimes I get in the car and step on that little thing and it won't start." Mr. Oetting's curves are very illuminating as to the battery conditions back of the "little thing", which explains its apparent aversion to rolling over the engine in mid-winter. Probably no other part of an automobile will repay more fully a little care and a little time spent in understanding it than the storage battery and yet hardly a part is so little understood. For this reason Mr. Oetting's article is heartily endorsed as making for still greater popularity of electricity in this, one of its newest fields.

A. M. DUDLEY

Pooling Our Resources

The war has shown the advantages of unified operation of large units of organization, and shown them so convincingly that it is hardly probable that we shall ever return to the old order of things. This is being exemplified in co-ordinated operation of various utilities of necessities, such as the railroad, telephone and telegraph systems. In the power field, systems of transmission have already grown to large proportions and to such an extent that in numerous cases they are serving contiguous territory. In various parts of the country there has already been considerable linking together of systems of distribution with resultant economies, and insurance of service.

One of the outgrowths of the recent working together of all interests in a common cause to accomplish a definite object should be a better type of corporate consciousness, working towards the best interests of the nation as a whole rather than being limited narrowly to the interests of a single corporation. If millions of tons of coal can be saved to the nation annually by taking advantage of known engineering methods, there should be some way of bringing about such savings, and without encountering legal interference. Last month at the Ohio Electric Light Association Convention the statement was made that "Engineers owe it to their country to use its power producing equipment in such a way that the greatest amount of power will be generated at the lowest possible cost." From the engineering and economic standpoints, there is no question but that neighboring power systems should be interconnected and the small or inefficient stations eliminated. In some cases, such paralled operation may have to wait suitable legislative action. However, as President Theodore N. Vail, of the Bell system says in his annual report just issued, "Initiation is in the province of operation. Initiation must come from familiarity, continuous intimate association with an observation of operation." The Bell system, with its 23 000 000 miles of wire system, furnishes an example of interconnection that will probably never be equalled by any power system. Undoubtedly the solution of the problems incident to the generation and distribution of power should be worked out by the electrical industry itself without waiting for outside assistance or interference. Steps should be taken towards making the legal solution agree as far as possible with the engineering solution.

The present seems to be an unusually opportune time for the electrical industry to show its power of initiation by analyzing its problems and determining the possible improvements in operating conditions, along with the obstacles, legal, financial or otherwise, which interfere with the immediate realization of the solutions which would be in the interest of national economy. Some progress apparently is being made looking towards the making possible of further hydroelectric developments. But the whole power problem should be studied and worked out along lines of broad national policy. It would seem that this general subject is one to which the National Electric Light Association, which meets in annual convention next month, can well devote special attention. It might go even a step further and establish a code of ethics for its members as a society whose first aim is to live up to its name as a national society—one which works for the best interests of the nation.

A. H. MCINTIRE

New South Philadelphia Plant

Of the Westinghouse Electric & Mfg. Company

H. T. Herr
Vice-President,
Westinghouse Electric & Mfg. Company

DEVELOPMENTS in electric generating machinery, and the increasing demands for apparatus for the generation, distribution and utilization of electric current have lead to an unprecented increase in the building of steam turbines, condensers and auxiliaries. Close relations have always existed between the Westinghouse Electric & Mfg. Company and The Westinghouse Machine Company in the production of prime-mover apparatus for the generation of electric current and general power purposes, and the increasing demand for units which were a product of both companies lead to their consolidation.

The development and introduction of geared turbine and auxiliary machinery of appropriate proportions for ships of any character was undertaken some ten years ago by The Westinghouse Machine Company on a large scale, and through the foresight and courage of the late Mr. George Westinghouse, the construction of successful geared-turbine units of large power for ship propulsion increased enormously the demand for steam turbines, reduction gears and condensers. More recently electricity has been applied to the propulsion of ships by means of turbogenerators and motors. These developments, as well as the general expansion of the electrical business, have made necessary large expansions of the productive capacity of the Machine Works of the Westinghouse Electric & Mfg. Company.

The expansion and growth of the East Pittsburgh shops has shown the necesity of more room in the handling of materials and manufacturing operations. A review of the congested conditions that confronted the Company in its East Pittsburgh manufacturing plants, which covers approximately 53 acres, indicated that no large plant extensions could be made at East Pittsburgh, primarily because no desirable land for manufacturing purposes is available there, and secondarily because, with the employment of some 25 000 men at the East Pittsburgh Works, it was considered more practicable to institute a new industrial center to take care of the probably large future shop requirements of the Company.

Inasmuch as a new industrial development seemed necessary, and the character of the equipment which would be manufactured was quite well determined, the writer was detailed to prepare a general plan for a plant adequate to meet the immediate needs of the Company's business, as well as to provide for large future extensions, and to ascertain the most desirable location for such plant construction. This work was undertaken in the summer of 1916. In the acquisition of the property for the new plant, the need of ample ground space was recognized, and the general layout of the new shops was made to take care of the difficulty which fifteen years' growth at East Pittsburgh had made quite apparent. Also the character of the products to be manufactured in the new plant made imperative an adequate and good water supply.

FIG. 1—GENERAL VIEW OF SOUTH PHILADELPHIA WORKS

The property at South Philadelphia was located after a thorough investigation of many sites in different parts of the eastern states, it being considered important that the site should be selected with a view to a centralized location of the activities to which the apparatus to be manufactured was to be applied, as well as to the problems of operation and the employment of labor necessary in the future manufacturing operations of the new plant. These investigations finally led to the acquisition of some 500 acres of land on the Delaware River about nine miles south of Broad Street Station, Philadelphia. With the acquisition of the property in the latter part of 1916, the general layout was worked up, and the construction of the initial plant was authorized in January 1917.

LOCATION OF SOUTH PHILADELPHIA WORKS

The general location of the property acquired for the construction of the new works at South Philadelphia is shown in Fig. 2. The detail map, Fig. 3 indicates the extent of the property holdings, and Fig. 4,

the layout of the first development of the new plant. The property is reached by the double-track trolley service of the Chester Short Line of the Philadelphia Rapid Transit Company, from either the subway at Broad Street Station, Philadelphia, on the northeast, or from Chester on the southwest. There is a frontage of over 4500 feet on the Delaware River, which has been reserved for future industrial development, while the present construction has been limited to the higher ground lying between the Reading Railroad to the north and the new line of the Pennsylvania Railroad to the south, as indicated in Fig. 3. The location insures an adequate supply of fresh water from the Delaware River for the operation of the power house and the testing of steam turbines after their manufacture, and also the necessary service water supply for the comprehensive plant as planned.

The property north of the Philadelphia & Reading Railroad and the Chester Short Line has been reserved for a town site development. This land, as well as the property on which the first shop buildings have been erected, has the highest elevation of any land lying south of Darby Creek and east of the Reading Railroad, and has been found suitable for heavy foundations without piling, an important consideration in the construction of the heavy shops contemplated in the first development plans.

FIG. 2—MAP OF PHILADELPHIA DISTRICT
Showing the location of the plant.

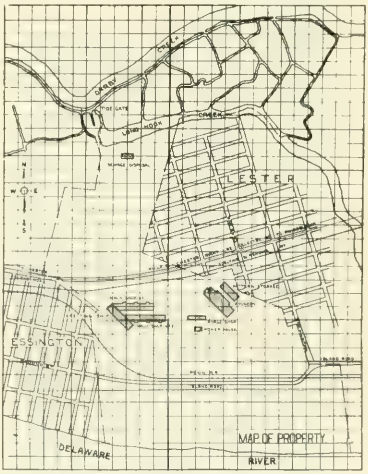


FIG. 3—MAP OF THE COMPANY'S PROPERTY AT SOUTH PHILADELPHIA

The town site on the high ground north of the Reading Railroad will, when fully developed, take care of approximately 5000 people, leaving for future extensions of the plant not only those shops which are provided for in Fig. 4, indicated in dotted lines, but also the property lying south of the Pennsylvania Railroad to the Delaware River front and that portion of the property to the north of the town site bordering on Darby Creek, both of which latter tracts are, with suitable improvements, open to deep water, and consequently the main channel of the Delaware River to the Atlantic Ocean. An independent trolley line gives service from the cross-town lines of Philadelphia to the Island Road south of the present plan of shop development. The property in general is thus served by the Philadelphia and Chester Short line of the Philadelphia Rapid Transit Company and the Reading Railroad to the north and the Pennsylvania Railroad to the south and west, as well as deep water service from the Delaware river frontage to the south and Darby Creek to the north. Although the river has a tide of approximately five feet, the water in the Delaware River at this plant is not brackish, as no salt water is apparent at any time north-east of Chester.

LABOR CONDITIONS

The previous development of the Baldwin Locomotive Works at Eddystone, supplemented by the Eddystone Munitions Corporation and the Remington Arms Company, has indicated the suitability of this section for transportation and general adaptability to the securing of adequate labor demanded by large industrial establishments.

It had been considered that no housing development would be necessary at the new plant of the Company because Philadelphia offers a splendid labor market for workmen of the type to be employed at the new plant, and the transportation facilities seemed adequate to insure suitable conditions for the movement of labor from Philadelphia, Chester and the suburbs lying between these two centers to the north of the property. During the construction of the plant, however, through the urgent need for shipbuilding, the American International Corporation located a large shipyard at Hog Island to provide ships for the Emergency Fleet Corporation. On account of its magnitude, this project has necessitated the employment of thousands of men,

which was not contemplated in the consideration of transportation of labor to the new plant of the Company; and while the latter part of the construction and the initial operation of the plant were considerably interfered with on this account, provisions have been made to provide suitable relief from this congestion, and to take care of the requirements at both plants. The Philadelphia & Reading Railroad now has double track service between Philadelphia and Chester, and the Pennsylvania Railroad, through its initial extension to Essington before the Hog Island plant was contemplated, has also constructed a double track line to serve both of these plants. With these improvements in transportation facilities, largely constructed for freight purposes, the movement of materials in and out of the plant is adequately taken care of, and the transportation of labor, both by rail and trolley, has been bettered with improvements in the double-track trolley service to the Chester Short Line and the contemplated improvements of the trolley service on the Island Road. The new plant is therefore admirably located with reference to transportation facilities for handling both the employees and the freight and express service which is necessary to the plant operations.

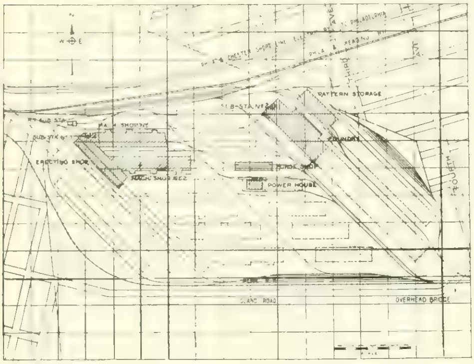


FIG. 4—PLAN OF PLANT

The shaded areas represent completed buildings, and the dotted lines indicate future extensions.

FIG. 5 PATTERN STORAGE BUILDING

PLANT LAYOUT

The character of the apparatus to be manufactured at the new plant was quite well established at the time the work of making the initial plans was undertaken. A careful study was made of the general plant arrangements, both for immediate needs and future extensions which comprehended primarily the operations of the plant in the construction of heavy and light machinery of a known type. The shop appliances, crane capacities, heights of cranes, runways and general dimensions of the shops proper were arrived at from the experience secured in the operation of the East Pittsburgh plant, and the departments of the plant were decided on from the nature of the product to be manufactured. The buildings to be provided therefore comprised a pattern shop with suitable pattern storage, an iron foundry capable of handling large and small castings, a power plant for the generation of power and steam for testing purposes, a forge shop to provide suitable forgings for the character of the work to be undertaken, a machine shop and an erecting shop, as well as suitable facilities for offices, the storage of materials and provision for the clerical force necessary in the operations.

In studying the general shop arrangements, numerous schemes for the buildings were laid out and considered, and the shop-plans shown in Fig. 4 were finally decided on.

FIG. 6—VIEW OF THE TOP FLOOR OF THE PATTERN BUILDING

All the machines on this floor are individually driven, there being no exposed overhead belts or wiring. All the machines have pneumatic dust and shaving extractor connections. Ample daylight illumination is provided by the sawtooth roof construction, as well as the side windows. In this as well as in all the other buildings, artificial lighting with units of the most modern type is provided for overtime or night work.

The arrangement of the buildings is unique and particularly suitable for the handling of materials in and out of each shop and storage space with standard gage railroad tracks. The machine shops communicate directly into the erecting shop, an arrangement which is similar to other large plants, but is unique in the angle at which the respective shops are placed to each other. Too often in the layout of large industrial plants, insufficient consideration is given to the yard tracks and, when too late, it is discovered that the curvature necessary in yard trackage is too short for the handling of cars and locomotives without continual difficulty and high maintenance cost. The 45-degree angle gives easy curvature from the main leads, running between the Reading and Pennsylvania Railroads, into the shop buildings and yards, and access can be had to

any of the various shop buildings proposed. Another important feature of the 45-degree connection between the erecting and machine shops is the fact that free access is given from the machine shops into the erecting shop both on the ground floor and balconies, and at the same time the triangular space created by the joining of the machine shops to the erecting shop, gives space for offices, heating fans and handy storage of materials used in manufacturing operations. In each of these triangles there is provided a four-story building consisting of ground and balcony floors, a mezzanine floor between, and a floor above the balcony level, each triangle being served by stairways and elevators, and providing space for offices, toilets and storage. In addition, each machine shop has three service bays for toilet facilities and for the heating apparatus. Particular attention has been paid in the construction of the plant to the comfort of the employees, the facilities provided being of the best type and most conviently arranged.

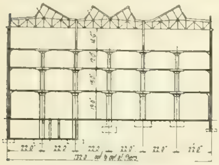


FIG. 7—ELEVATION OF PATTERN STORAGE BUILDING

BUILDINGS

A cross-section of the pattern shop and pattern storage building is shown in Fig. 7. This is constructed of reinforced concrete and tile with steel roof trusses throughout. The floors are of reinforced concrete. The present building is 400 feet long. The pattern shop comprises the south-east half of the top floor, is splendidly lighted, is equipped with the most modern tools, and the very best facilities are provided for the comfort of the workmen. The north-west portion of the top floor is devoted to the general office work. The other three floors are provided for pattern storage, a portion of the first floor being taken for the construction and repair of foundry equipment. The basement is utilized for the storage and mixing of sand for the foundry. Communication between this portion of the pattern storage building and the foundry is obtained by large tunnels for the handling of the sand from the storage basement into the different bays of the foundry. This feature is a most important and convenient one, and provides large storage capacity and excellent facilities for handling foundry sand and overcomes difficulties incident to the usual method of handling this material. This basement is served by trackage both inside and outside the building.

The pattern shop is served by a freight elevator 20-feet square and able consequently to handle the largest patterns from the pattern shop or storage space to the foundry floor. A second freight elevator about eight by eight feet, and a passenger elevator for the office space completes the elevator equipment. The building is served at two ends with ample stairways, and a stairway is also provided around the passenger elevator in the center of the building on the north-east side. The lighting and ventilation of the top floor is most excellent, both for the pattern shop and for the offices and drafting room.

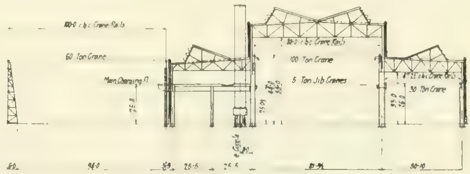


FIG. 9—ELEVATION OF FOUNDRY

FOUNDRY

Fig. 9 shows a typical cross-section of the foundry looking northwest. This building is of steel construction with one main bay having an 80 foot crane span carrying 60 and 100 ton cranes with three five ton jib cranes on each side. In the center of the foundry are three cupolas with suitable charging floor, blower equipment, elevators, etc. Three air furnaces are provided on the ground floor in the 50 foot side bay adjacent to the cupolas.

The melting department is located in the center of the south-west side bay, allowing a space at either end of this bay, served by 20 ton cranes, for medium size castings. The 50 foot side bay to the northwest of the foundry is served by 20-ton cranes and is utilized for core making and brass work. The core ovens are housed in an additional bay, which also provides for a foundry store room, blacksmith shop, metallurgist's quarters with chemical laboratory, testing machines, etc., and offices for the supervisory force. At the north-west end of the foundry suitable grinding, cleaning and sand blast rooms are provided for both brass and iron with adequate dust collecting appliances. Track scales are provided at each end of the foundry for weighing out the finished castings, and the general

FIG. 8—GENERAL VIEW OF FOUNDRY

equipment of the foundry with respect to molding pits, etc. is of the most modern type. This building is 650 feet long, and at the south-west side of the foundry a 100 foot span with a 60 ton crane runway is provided for flasks and foundry materials.

POWER HOUSE AND FORGE SHOP

A cross-section of the power house and forge shop is shown in Fig. 10. The power house is equipped with

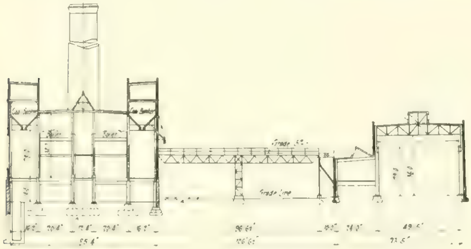


FIG. 10—ELEVATION OF POWER HOUSE AND FORGE SHOP

six 600 h.p. Sterling boilers and three 1500 kw non-condensing turbogenerators, with switchboard, lightning arresters, etc. All of the buildings are connected by large concrete underground tunnels in which the heating, steam, water, air and service piping are carried. Provision is made in the power house for the handling of coal to the coal bunkers from suitable pits below the surface tracks; also provision is made for the handling of the ashes from the stokers into suitable overhead ash bins which discharge their contents directly into cars placed outside of the power house.*

In Fig. 10 the forge shop is also shown. The cranes in the forge shop and in the side bays of the foundry are interchangeable. The forge shop is provided with one 1000 ton steam-hydraulic press and one 350 ton steam-hydraulic press. There is a 1500 lb. hammer, four heating furnaces, (two large and two small), two annealing furnaces, and suitable hand forges, case hardening equipment and tool dressing appliances. The heating and annealing furnaces are served by hot-blast gas producers, the coal for which is handled on the overhead runway directly from the power house coal bunkers. Suitable bolt heading, forging and tool dressing equipment is provided, together with adequate sanitary provisions for the care and comfort of the workmen. The forge shop as at present constructed is 350 feet long.

FIG. 11—INTERIOR OF FORGE SHOP

*Details regarding the electrical equipment, the method of distributing the current, and the power and lighting equipment are given in an article by Mr. Graham Bright in this issue.

MACHINE SHOPS

The two machine shops now built are made right and left hand, are 750 feet in length and each comprises an 80-foot main bay, a 40-foot side bay, and a 40-foot balcony with three service bays to each shop for housing heating equipment, toilets, locker rooms, elevators, etc. An 80 foot crane runway is provided between the machine shops for the storage and handling of materials. Fig. 14 shows a typical cross-section of the two machine shops. The main bays are served by 30 and 50 ton cranes, and the side bays by 6, 10 and 20 ton cranes, and the balconies with 3 ton cranes. Owing to the construction of the shops, the very best lighting effects are obtainable throughout, and for light work the balconies afford most excellent manufacturing space. The height of these balconies is a feature well worth noting. The side bays were extended to the height of the main bay roof trusses for building strength and lighting arrangement.

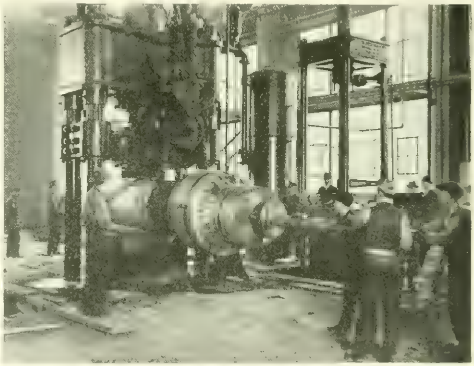


FIG. 12—HYDRAULIC FORGING PRESS

Shown forging a shaft. The motor-driven turning rig just in front of the press is spring supported from an overhead crane.

The buildings are constructed of steel, tile and glass with concrete main floors paved with asphaltum block, the balconies being reinforced concrete with a coating of asphaltum material. Both the main side bays and balconies of the machine shops communicate directly with similar floors in the erecting shop, the triangles being utilized as previously described.

ERECTING SHOP

In Fig. 15 a typical cross-section of the erection shop is shown. This is identical in crane appliances, height, etc. with the machine shops. To the southwest of the erecting shop an 80 foot crane runway of 50 tons capacity is provided. All cranes in the main bays of

the foundry, machine and erecting shops are interchangeable, as well as the crane runways between the machine shops and adjacent to the erecting shop. The cranes in the side bays of the foundry and forge shop are interchangeable. The crane runway to the southwest of the foundry is 100 foot span. In addition to the overhead cranes in the erecting shop, there are also provided three 5 ton jib cranes. The erecting shop is approximately 550 feet long

Two dispensaries, which are really minature hospitals, are maintained at locations within easy reach of the men. Trained nurses, who take complete care of all minor cases and give first-aid attention when serious accidents occur, are always in attendance, and a physician visits the plant each day and is ready to answer emergency calls at any time. Arrangements are made with a local hospital for rapid ambulance service and the treatment of both surgical and medical cases. All workmen are instructed and urged to report to the dispensaries even for the most trivial accidents and ills.

FIG. 13—EXTERIOR VIEW OF MACHINE SHOPS

Adequate provisions are made for the testing of steam turbines of various capacity, as well as the testing of condensers and pumps. The erecting shop is also provided with facilities for erecting and testing reduction gears.

Special attention has also been given to fire prevention. All the buildings are absolutely fireproof. Those of more than one story have several fire towers; and store rooms are divided by fire walls with automatically closing fire doors. A complete sprinkler system is installed, supplemented by numerous chemical extinguishers. A fire crew, in charge of a fire marshall, holds regular weekly drills and is especially trained in the method of handling fires.

SAFETY FEATURES

Every safeguard that modern engineering can suggest, has been utilized to prevent accidents and protect the workmen. Among the more important safety measures, are the following:—

The department of safety engineering forms an important division of the shop organization. This department not only studies the subject of safety, but supplies safety appliances wherever necessary. As there is not a line shaft or an exposed belt in the plant, a most serious hazard found in many plants does not exist. Where belts and gears are necessary, they are protected by guards as shown in Fig. 19. There are no exposed electrical contacts that can be reached by the ordinary workmen. Enclosed switches and pushbutton controllers are used in connection with the motors; all lighting panels are of the safety type; and all resistors and other usually unprotected electrical parts are enclosed with wire screens. The chains of all cranes are regularly inspected and links or other parts showing the slightest defect are replaced immediately. Circular saws, grinding wheels, etc. are provided with guards Guard rails surround all furnaces and moulding pits. All chippers in the foundry are compelled to wear goggles.

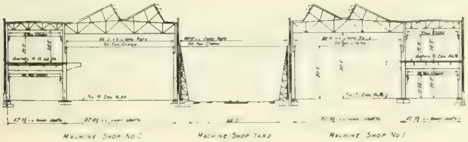


FIG. 14—ELEVATION OF MACHINE SHOPS

HEATING AND VENTILATION

The machine shops, erecting shop, and foundry are heated and ventilated in winter by the indirect blower system. Each shop is equipped with two large steel blowers, which supply heated air and have sufficient capacity to change all the air in the shop once an hour. The air can be taken directly from the outside or (except in the case of the foundry) in extremely severe weather the warm air inside the shops can be recirculated. For the foundry, outside air is always used because of the smoke and fumes incident to the operations.

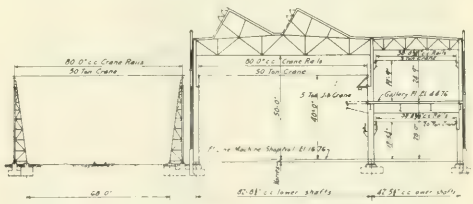


FIG. 15—ELEVATION OF ERECTING SHOP

Inside offices and toilets are ventilated by means of exhaust fans which change the air every ten or fifteen minutes. All the offices are heated by steam radiators, as are also the toilets in the shops, so as to prevent the freezing of the water pipes in case the blower system should be shut down.

WATER SUPPLY AND SEWERS

The water supply for the plant is provided from the Delaware River at the extreme south-west line of the property. Two seven foot tunnels lead to the erecting shop, a connection being carried from these tunnels to the power house with 30 inch concrete piping. A forebay or basin is provided for settling the mud and silt in the intake tunnel near the Island Road. These seven foot tunnels pass under the erecting shop to the turbine testing floor and provide an adequate supply for any testing operations which may be carried on in this shop. The outlet tunnel also serves as a storm sewer for the entire property, and this work was put in permanently to take care of the complete plant development. Suitable sanitary sewers are also provided looking to the complete future extensions, and a sewage disposal plant has also been provided near Darby Creek on the northern part of the property. This plant is not only adequate for taking care of the present shops, but by provision for extensions will serve the complete future extensions of the plant proper, as well as the town site. By the use of underground conduits and the tunnel system on the plant proper, no wires, pipes or other obstructions are above ground. The property has been graded to an elevation of 16 feet above high water, and the work done in the initial installation has been entirely of a permanent character to take care of the complete layout.

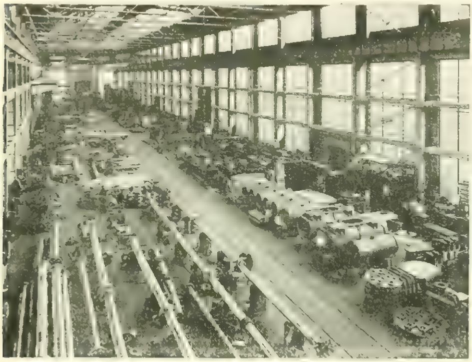


FIG. 16—INTERIOR OF MACHINE SHOP NO. 1

These shops are entirely free from exposed belts, or overhead wiring, all of the machines being equipped for individual motor drives. The shafting for merchant vessels shown in the foreground is forged and turned at the works. A group of surface condensers for merchant vessels is shown at the right.

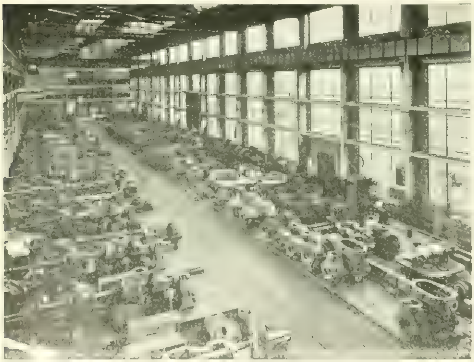


FIG. 17—INTERIOR OF MACHINE SHOP NO. 2

The horizontal boring machines in the foreground, which are boring turbine casings, are all individually motor-driven. The gear hobbing machines for the turbine reduction gears can be seen in the background. A noteworthy feature of these machine shops is the special provision for securing ample daylight.

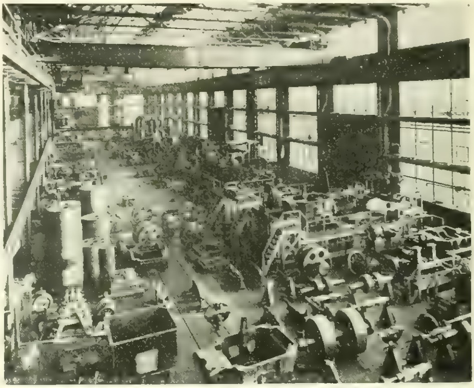


FIG 18—ERECTING DEPARTMENT, TURBINE TEST FLOOR

CONSTRUCTION WORK

In order to carry on the construction of this work after the location of the property had been determined and the preliminary plans arranged, a contract was made with Westinghouse, Church, Kerr & Company to construct the plant. The preliminary plans were turned over to this Company, and the method of handling the construction, authorized by Mr. E. M. Herr, the President of the Company, was arranged. Mr. Calvert Townley, assistant to the president, handled all busi-

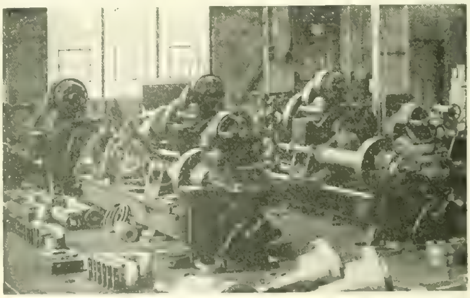


FIG 19—METHOD OF SAFEGUARDING LATHE GEARS

The lathes are individually operated with push-button controllers. The controller, shown in the foreground, is enclosed in a metal box with expanded metal door. All gears throughout the entire works are enclosed as shown above.

nes relations with Westinghouse, Church Kerr & Company.

As has been previously stated, all of the machine tools installed in the plant are individual motor drive, are new and of the most modern type. The initial plant is now complete and in operation. The general plans were at all times subject to advice and criticism

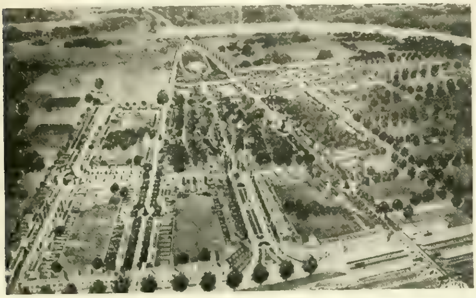


FIG. 20—ARCHITECTS PERSPECTIVE VIEW OF TOWN

of the writer's operating staff at East Pittsburgh and Trafford, as well as the engineering staff of the Westinghouse Electric & Mfg. Company and Westinghouse, Church, Kerr & Company.

THE HOUSING DEVELOPMENT

The community of houses for the plant's employees, known as South Philadelphia, is located on the Company's property north of the plant and on the other side of the Chester Short Line trolley tracks. Work was begun on this development in the summer of 1918 and by January 1st, seventy-five houses were completed and several hundred more were well under way. The streets of this development are broad, lined with trees,

FIG. 21—ONE OF THE STREETS ON THE COMPANY'S PROPERTY

and provided with a dual system of sewers. In the finished plan there are to be numerous open squares, and play-grounds, several churches, a school, a row of stores and over a thousand residences.

The houses are built on sodded terraces, in rows of two, four, six, and eight. All are of the highest grade of construction and are built mainly of brick, with some of hollow tile and stucco for variety, but none of frame. The roofs are of slate and the cellars are concrete. All the houses have porches in front and gardens in the rear. The interior furnishings are excellent, and include modern kitchens, bathrooms, heating equipment,

FIG. 22—TYPICAL GROUP OF HOUSES

electric lights, high grade wall paper and shades, and other aids to comfort and convenience. Most of the houses have six rooms, but some are smaller or larger. They will be sold or rented to Westinghouse employees only and are subject to restrictions that will always keep the community a desirable residential district.

The writer has given only a general outline of the plant; special features are more intimately discussed in articles appearing in other pages of the JOURNAL. In passing, it should be stated that the entire facilities of these new works now are engaged in the construction of marine propelling machinery for the ships being built by the Submarine Boat Corporation and the Merchant Shipbuilding Corporation, as agents for the Emergency Fleet Corporation, and torpedo-boat destroyer machinery consisting of turbines and reduction gears for the United States Navy.

Manufacturing Scheme of the South Philadelphia Works

Oscar Otto,
General Superintendent

FOR the time being the entire facilities of the South Philadelphia Plant are being devoted to the manufacture of marine turbine equipment, consisting of turbines, gears, condensers and auxiliary equipment, for driving the boats of the Submarine Boat Corporation and the Merchant Shipbuilding Corporation; both being agents for the United States Emergency Fleet Corporation. While these two equipments vary considerably in their details, yet in general it may be said that the complete organization is concentrated on the manufacture of a single product. The propulsive equipment for the boats of the Merchant Shipbuilding Corporation consists of a cross-compound turbine driving a single propeller through a two-pinion double-reduction gear, while for the Submarine Boat Corporation, the turbines are of the complete expansion type driving a single propeller through a single pinion double-reduction gear.

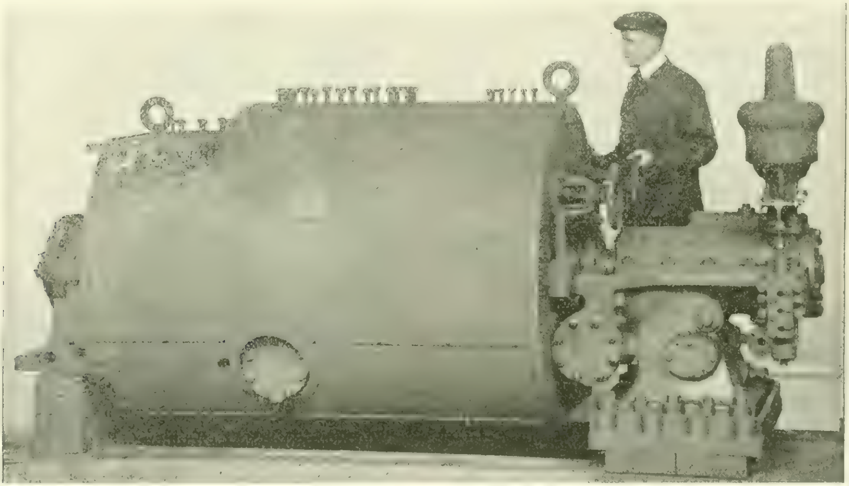


FIG. 1 HIGH PRESSURE ELEMENT OF STEAM TURBINE FOR MERCHANT SHIPBUILDING CORPORATION

The high and low pressure elements of the turbines for the boats of the Merchant Shipbuilding Corporation are shown in Figs. 1 and 2. Both the high pressure turbine spindle and the low pressure spindle, Figs. 3 and 4, respectively, are of the single flow reversing type, the impulse wheel on the left being the reversing element. The high pressure turbine is of the combination type, steam first entering the impulse element on the right, Fig. 3, and then expanding through the several rows of reaction blading shown on the left of the impulse element. The low pressure element is a straight single-flow turbine, steam entering the first row of blades on the right, Fig. 4, and expanding through the several rows of reaction blading, finally reaching the condenser.

The reduction gears driven by these turbines are of the two-pinion double-reduction type illustrated in Fig. 5. In this case the reduction is approximately 40 to 1. To the large flange of the second reduction gear the propeller shaft is attached with the propeller at its outer end. The steam after leaving the low pressure turbine passes to the condenser. This condenser is of the usual surface type and is equipped with a LeBlanc air ejector and turbine-driven circulating pump.

The vessels built by the Submarine Boat Corporation are driven by a single complete expansion turbine having a reversing element similar in construction to the high pressure turbine shown in Fig. 3. The reduction gear for the Submarine Boat Corporation is of the single-pinion double-reduction type having the pinion on top. The condenser equipment of these vessels is similar to that of the Merchant Shipbuilding Corporation previously mentioned.

THE ORGANIZATION

The organization by which the manufacture of this product is to be effected is shown in diagramatic form by the following:

Sup't. Plant Maintenance Department
New Construction Division
Maintenance of Buildings and Grounds Division
Power Plant Operation & Maintenance Division
Fire & Police Division
Electrical Maintenance Division

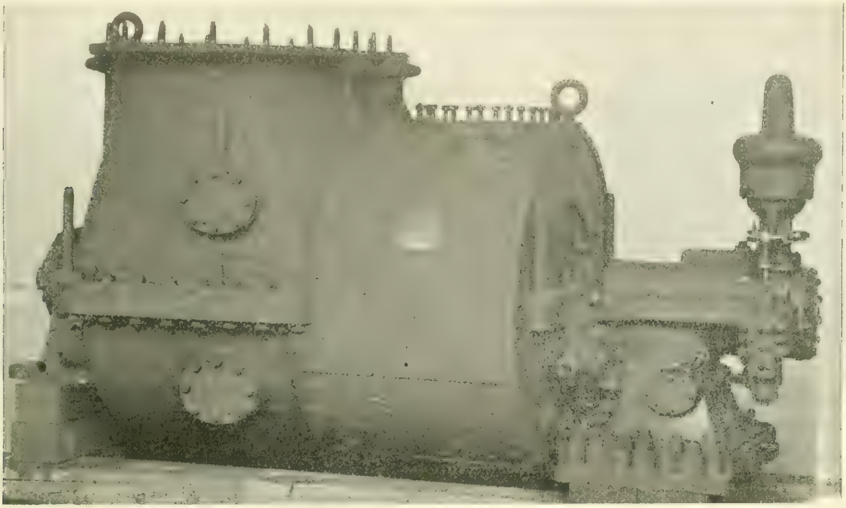


FIG. 2—LOW-PRESSURE ELEMENT OF STEAM TURBINE FOR MERCHANT SHIP BUILDING CORPORATION

Vice-President
Assistant to Vice-President
General Superintendent
Sup't Order & Supply Department
Stores Division
Order Division
Parcelling Division
Receiving Division

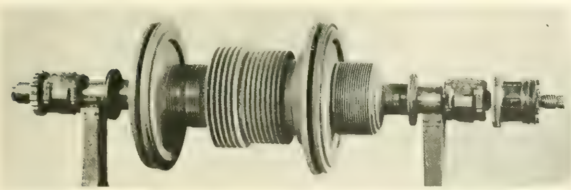


FIG. 3—HIGH-PRESSURE ROTOR

Sup't. Pattern & Foundry Department
Pattern Shop Division
Iron Foundry Division
Brass Foundry Division
Metallurgical Division
Sup't. Forge & Machine Department
Forge Shop Division
No. 1 Machine Shop Division
No. 2 Machine Shop Division
Sup't. Erecting & Testing Department—Turbine
Erecting Shop Division
Testing Shop Division
Sheet Metal and Pipe Division
Sup't. Erecting & Testing Department—Gears
Erecting Shop—Gear
Testing Shop—Gear
Erecting Shop—Condenser
Testing Shop—Condenser
Sup't. Tool Maintenance & Equipment Department
Tool Design Division
Tool Room Division
Tool Repair Division
Tool Setting Division
Steam Transportation Division
Janitor Division

Supervisor of Manufacturing Operations
Supervisor of Production
Supervisor of Employment
Supervisor of Inspection
Purchasing Agent
Works Accountant
Cost Division
Payroll Division
Shop Time Keeping Division
Paymaster & Cashier
Supervisor of Welfare
Relief Division
Workmen Compensation Division
General Welfare Division
Supervisor of Education
Chief Engineer
Engineer Large Turbine Department
Engineer Small Turbine Department
Engineer Gear Department
Engineer Condenser Department
Consulting Engineers
Traffic Manager and Shipper
Photographer

THE MANUFACTURING LAYOUT

Since the product which is to be manufactured at the South Philadelphia works is of such a nature as to lend itself to quantity production, the machine and erecting shops have been arranged with this in mind

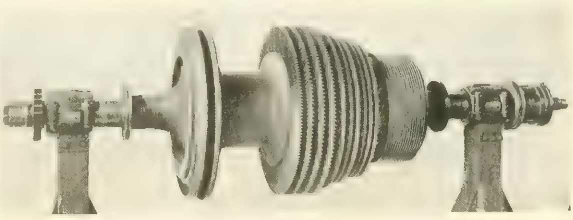


FIG. 4—LOW-PRESSURE ROTOR

in order to secure the most economical production. The plan of operation is as follows:—

The castings, forgings and purchased material are delivered to the machine shops in sufficient quantities to keep the various machines constantly performing the

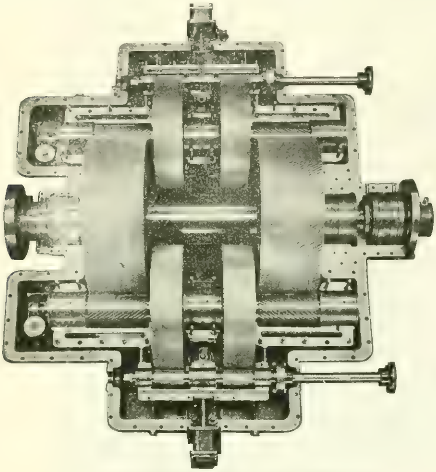


FIG. 5—TWO PINION DOUBLE REDUCTION GEAR

same operation until the lot is completed. The aim is to set up the machine tools in such a manner that the proper sequence of operations on each piece can be performed with the least amount of handling. The shops are so arranged that the castings and other material can be sent either directly to the various machines or can be stored in the yard between the machine shops. From here the rough material can be sent to the various machines. A standard gage track runs

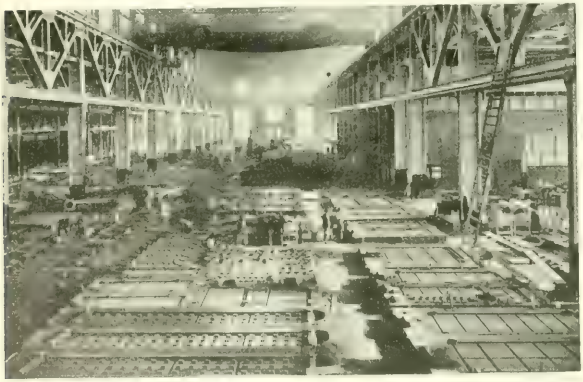


FIG. 6—GENERAL VIEW OF FOUNDRY MELTING DEPARTMENT
Containing three cupolas of a combined capacity of 180 to 200 tons per day.

through each building and a number of electric locomotives with trailers haul material to and from the several departments.

On account of the extreme accuracy required, the machine tools are the best obtainable and are equipped with individual motor drive and where deemed necessary, with quick power traverse.

The following is an outline of the proceedure followed in lining up the operations and establishing piece prices:—

After the designs are made, bills of material together with blue prints covering the apparatus to be

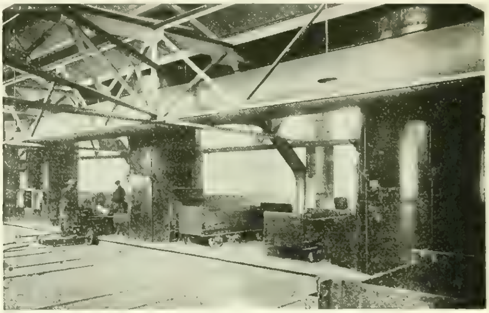


FIG. 7—CHARGING FLOOR FOR CUPOLA FURNACES
The cars are brought up on elevators, and by means of a transfer table any car can be dumped into any cupola.

built are sent to the scheduling department by the blue print distributing department. A print of all drawings is also sent to the jig designing department. A jig committee composed of a representative of the office of the director of manufacturing operations and one from the office of the superintendent of tools and fixtures devise means for the most economical manufacture of each piece. Jigs and fixtures are then provided and the scheduling department advised, who with this information line up the various operations in detail, recording them on "Master operation cards" showing the source of supply and the departments to perform the various operations. The cards are then turned over to the rate department where the piece price is either estimated, established from previous records of similar pieces or from time studies of the actual performance in the shop and the price entered on the "Master operation card." The cards are then returned to the scheduling department where scheduling or order sheets are made up for each department showing only such operations as are to be performed in that department.

THE FOUNDRY

The melting department contains three cupolas, Fig. 6, having a combined capacity of 180 to 200 tons per day. The charges are made up in the yard on trucks, delivered to the elevator and taken to the charging floor where by means of suitable trackage the trucks are stored till required. When charging, the loaded trucks may be taken to any of the cupolas by means of a transfer truck.

The large cupolas are equipped with pneumatic charging tables Fig. 7, by which the truck, having been placed on the charging table, is discharged by the tilting of the table through the action of compressed air. Each cupola is equipped with an individual blower.

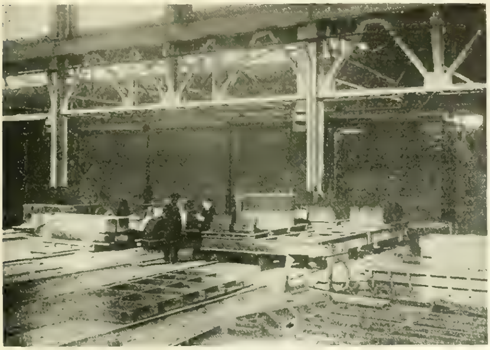


FIG. 8—CORE SHOP

Equipped with foundry core baking ovens. The cars are provided with a cable grip, and a motor-operated cable pulls them into and out of the oven, so that it is not necessary for an attendant to enter the oven at any time, thereby saving time and heat. These ovens are located in the side aisle at the left of Fig. 6.

There are two air furnaces of 40 tons capacity each and one of 15 tons capacity. These are charged by means of a charging boom operated from the outside yard. This boom is provided with a counterweight on one end and the scrap is put on the other end. It is then lifted by the two trolleys on the yard crane, and by running these trolleys along the crane girder, the scrap may be placed in its proper position in the furnace without laborious work. These furnaces will melt large pieces of scrap weighing 20 to 25 tons apiece in other words, anything that will go through the charging doors. In cases of improper combustion pressure, air may be utilized to bring the iron to the proper temperature. These furnaces produce the most homogeneous iron that can be made in a foundry. The iron after being melted down is puddled under the slag until

FIG. 9—GROUP OF FINISHED REDUCTION GEARS

it is very thoroughly mixed and, when tapped off into a large ladle, there is a homogeneous mixture giving a much stronger iron than can be made by the cupola process.

The foundry is equipped with large concrete casting pits, strictly waterproof, with provisions for bolting down any large mold by means of large stirrups running from top to bottom and girders across the top. Castings up to 125 tons may be made and, when running full, the capacity will be in the neighborhood of 3-½ to 4 million pounds per month.

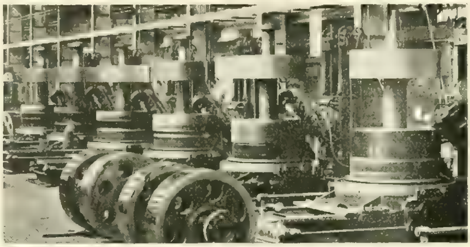


FIG. 10—GROUP OF MACHINES FOR TURNING GEAR BLANKS

The core shop Fig. 8, is equipped with an electric core puller, so that heavy cores and molds that are placed in the ovens to dry can be pulled in and out of the ovens without difficulty. Some of these cores weigh fifty tons apiece. The ovens are fired with coke and are so arranged that the coke is dumped from drop bottom cars directly into storage bins from which it is fed to the ovens. At both ends of the cleaning floor, the sand as it is dug out of the castings runs through a grating, thus keeping the chipping floor clear, the rods and coke being stopped by the grating and forked off. The sand is returned to the sand storage bin, which is under the pattern shop, by means of a storage battery truck operating through a tunnel connecting the pattern shop and foundry. These trucks are equipped with trays, containing the sand, and may readily be taken to any desired part of the foundry. The cleaning rooms, sand blast and rumbling systems are all equipped with a suction system for the removal of dust.

ERECTION AND TESTING DEPARTMENT (TURBINE)

The several parts of which a turbine is composed are tested individually by the department in which they

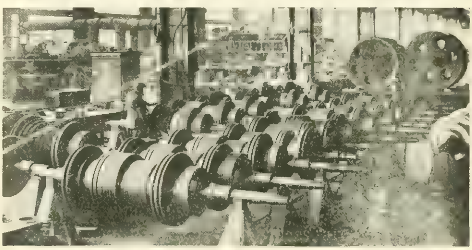


FIG. 11—TURBINE ROTORS STORED IN THE ERECTION SHOP

are made before being sent to the erection and testing department. This is to insure a greater degree of care on the part of the several production departments, and also to aid in speeding up the work of the testing de-

partment in that less faulty material will have to be returned for correction. The nozzle blocks, after being filed to the proper throat and exit areas, are fitted to their respective nozzle block chambers and then are given a hydrostatic test to insure the tightness of the joints. The nozzle block and chamber are then bedded in the turbine cylinder and are tested for tightness with steam under full boiler pressure. All parts such as governor, control and maneuvering valves, are tested for tightness after being assembled with steam under full boiler pressure.

The several component parts of the turbine spindles are each given a static balance test before being assembled. They are also balanced before and after blading to insure their correct operation before being assembled in the turbine cylinder. The final tests consist of operating with a brake under full load, pressure readings being taken at several points to determine the correctness of the steam distribution. The turbines are also operated at a speed of 20 per cent above normal to insure their absolute safety. After the final tests are passed, the unit is given a rigid inspection and, if passed, is prepared for shipment. The turbine test floor is designed to accommodate four large and four small turbines at one time, giving a total capacity of 24 turbines per month.

ERECTION AND TESTING DEPARTMENT (GEARS)

The main object of the reduction gear test is to determine if the cutting of the teeth and the alignment of the gears is sufficiently accurate. To determine this, the gear is driven by a suitable motor and the power transmitted is absorbed by a brake.

In case inaccuracies of machining are discovered during the testing period, such inaccuracies are corrected by scraping the tooth faces until a proper tooth bearing is attained. This requires patience and skill of a very high order. The gear testing department is equipped with eight testing pits having a total capacity of thirty gears per month.

Power System of the South Philadelphia Works

GRAHAM BRIGHT
General Engineer,
Westinghouse Electric & Mfg. Company

MANY of the large industrial plants of today have grown to their present size from much smaller plants, and the growth in such cases has been more or less spasmodic. The application of power and lighting to such a plant is often difficult, as the system first installed may not be adapted to conditions after numerous extensions have been added. Thus a considerable number of large industrial plants are today working under a handicap due to the fact that the power system which was adequate for the original plant, is not of the proper type for a large works extending over a considerable area.

In laying out the power and lighting system for the South Philadelphia Works, the engineers were fortunate in that the entire plant was tentatively laid out in advance, although only a portion of it has been erected. This procedure permitted the engineers to plan a power and lighting system that would be not only adapted to the original plant, but would also be flexible and well suited to the final installation.

The Philadelphia Electric Company supplies power and light to the City of Philadelphia and surrounding territory. The load during the winter months is somewhat greater than during the summer, so that naturally the power company has some surplus capacity during the summer months. This fits in very nicely with the power requirements at the South Philadelphia Works. During the winter months, all of the buildings must be heated, requiring steam at pressures from two to four pounds. This steam can be produced most economically by generating it at high-pressure and passing it through non-condensing turbines operating at a back pressure of from two to four pounds. During the summer months, no steam is required except for testing purposes. From these conditions, it will readily be seen that it would be to the mutual benefit of both the Philadelphia Electric Co. and the South Philadelphia Works for the power company to furnish energy during the summer months and for the South Philadelphia Works to make its own power during the winter months. It was therefore decided to install non-condensing turbines and generate all the power required during the winter months at a power plant located at the works. This arrangement has the added advantage of a reserve source of power available at all times to take care of emergencies. If desirable, the plant at South Philadelphia may even pump power back into the system of the Philadelphia Electric Co.

Owing to the fairly large area covered by the works, it was decided to generate power at 6600 volts, three-phase, 60 cycles, and to distribute at this voltage by underground cables to various substations located about the works. These substations contain step-down transformers from 6600 to 440 volts for all constant speed motors used for driving machine tools, compressors, elevators, etc. The compressors are driven by synchronous motors in order to utilize their power-factor correcting ability. Rotary converters are located in each substation to supply direct-current at 250 volts for operating cranes, variable-speed machine tools and variable-speed blowers for the cupola furnaces. These converters operate at approximately 100 percent power-factor and, with the assistance of the synchronous motors, will tend to counteract the rather low power-fac-

tor which is produced by the large number of induction motors operating the constant-speed machine tools and elevators.

The lighting system is entirely separate from the power system. Separate lighting transformers are installed in each substation, which reduce the voltage from 6600 to 440 volts, and three-phase lighting mains are carried through the works at 440 volts. The lighting transformers are located on the outside walls of the buildings at various points to supply the lighting circuits which operate at 110 volts. High efficiency tungsten lamps are used exclusively for the general illumination the sizes varying from 40 to 1000 watts.

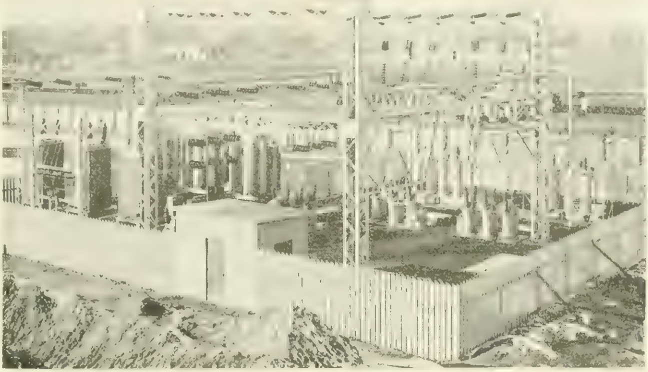


FIG. 1—OUTDOOR SUBSTATION

Showing lightning arresters, disconnecting switches, etc. The equipment is amply protected from interference by unauthorized persons.

The lighting system has been given special attention and the illumination of all buildings has been very satisfactory. Metallic enameled reflectors of both the straight and angle type are placed near the ceiling in both main and side bays of the foundry and machine shops. The angle reflectors increase the efficiency of the lighting system in that a considerable portion of the light that would otherwise be lost in adjacent aisles is reflected and directed to where it can be most useful. The offices are lighted by semi-indirect fixtures, the bowls being suspended by brass chains.

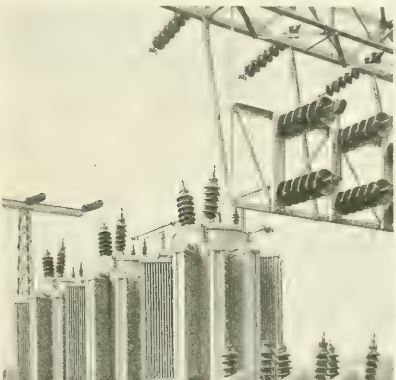


FIG. 2—DETAIL VIEW OF OUTDOOR SUBSTATION

FIG. 3—MAIN POWER PLANT

All high-voltage cables are three conductor, cambric insulated, lead covered, located in underground ducts and used to transmit power from the power plant to various substations about the works, and from the high voltage outdoor substation to the power plant. Fiber duct encased in concrete is used for the large cables. Control wires are also carried from the power plant to the outdoor substation by the underground system so that the outdoor substation can be operated from the power-plant switchboard. The power wiring in the power plant and substations is placed beneath the floor in fiber conduits and the control wiring is carried in metal conduits.

The low-tension distributing system throughout the works, both alternating and direct-current is generally

carried overhead but is placed in conduit where necessary. Single-conductor, cambric-insulated cables are used for the low-tension circuits and in many cases are carried through holes cut in the webs of the girders so as not to interfere with the cranes or piping system.

FIG. 4—BOILER PLANT
Equipped with automatic stokers.

The Philadelphia Electric Co. supplies power to the outdoor substation shown in Fig. 1, at 66 000 volts, three-phase, 60 cycles. This substation contains choke coils, lightning arresters, disconnecting switches, bus-bars, 66 000 volt oil switches and transformers for reducing to 6600 volts. The power at 6600 volts is carried to the main power station by underground cables. Fig. 2 shows the second set of transformers installed at the outdoor substation, consisting of three 2500 k.v.a., 66 000-6600 volt, single-phase, 60 cycle, radiator type, self-cooled transformers with oil circuit breakers and disconnecting switches. The transformers are mounted on rails placed on concrete piers and are so arranged that, by means of short lengths of rails, they can readily be rolled onto the top of a standard flat car which can

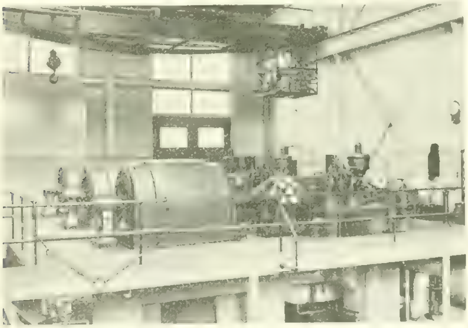


FIG. 5—THREE 1500 K.V.A., 6600 VOLT, NONCONDENSING TURBO-GENERATORS IN THE POWER HOUSE

be run in between the two groups of transformers. Any transformer can thus readily be removed for repairs in case of accident.

The main power plant, as shown in Fig. 3, is a fire-proof building arranged to be extended in the future when additional buildings are erected. In addition to supplying steam for the turbines, the boilers supply superheated steam for testing purposes in the erecting shop. Both high and low-pressure steam are carried to the various buildings from the power plant through underground tunnels. The boiler plant, Fig. 4, is equipped with automatic stokers which receive coal from overhead bins. The ashes are taken care of by means of an ash handling system in the basement.

The initial installation of turbines consists of three 1500 k.v.a., three-phase, 60 cycle, 6600 volts, 3600 r.p.m., noncondensing turbogenerator sets. Room has been provided for an additional installation of three 3000 k.v.a., turbogenerator sets. No condensing equipment is provided in the power plant. Fig. 5, shows a general view of the turbine end of the generating room, the space in the front of the view being available for the future turbines.

The main and auxiliary switchboards are located on the same floor with the turbines as illustrated in Fig. 6. The bus-bars, oil switches and disconnecting switches are located in the basement directly beneath

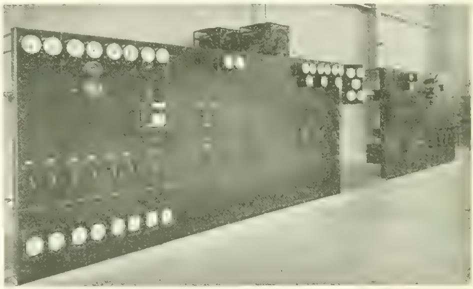


FIG. 6—MAIN AND AUXILIARY SWITCHBOARDS

the switchboard. The construction of this bus structure is illustrated in Figs. 7 and 8.

Fig. 9, shows the construction details of the floor under the switchboard and especially the fiber conduits which carry the main generator cables from the generators to the bus structure. This view also shows the reinforcing rods in place before the concrete is poured for the floor. Fig. 10 shows further construction details, including the metallic conduit used for the control wires which run between the switchboard and the generators and between the switchboard and the bus structure. A separate room has been built back of the switchboard over the reactance coil chamber to install transformers and rotary converters for a substation to provide alternating and direct-current power and lighting for the power plant itself and nearby buildings. All outgoing feeders are equipped with single-phase reactance coils to insure continuity of operation in case of short-circuit on any of the feeder circuits. Fig. 11 shows the reactance coil chamber which is located in the basement next to the switch and bus structure. These feeders are carried to distributing vaults at the

corner of the building from which they are led to the underground duct system.

An 80 ampere-hour electric storage battery, is located in the room back of the switchboard to insure operation of the switchboard at all times. This storage

FIGS. 7 and 8—BUS STRUCTURE
Located in the basement directly beneath the switchboard.

battery is kept charged by a small motor-generator set in the power plant.

Direct-current leads are carried from the power station to the outdoor substation for the purpose of closing and tripping the large 66 000 volt oil switches. The excitation for the turbogenerators is furnished by two 35 kw, 125 volt generators, one turbine driven and the other driven by a 440 volt, three-phase, 60 cycle induction motor.

Two sets of bus-bars are provided in the power plant and any feeder can be connected to either bus. Switches are provided so that one bus can be connected to the turbine in the power plant and the other to the transformers located at the outdoor substation. Both sets of bus-bars can be connected to either source of

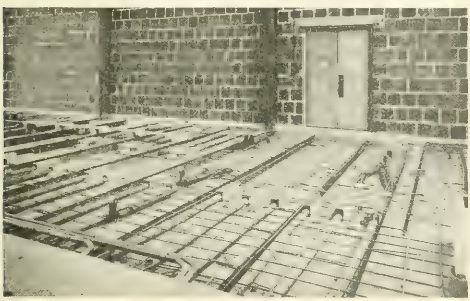


FIG. 9—CONSTRUCTION OF FLOOR UNDER THE SWITCHBOARD
Showing the fiber conduits.

power and, if necessary, both sources of power can be operated in parallel. Either bus-bar can be cut out for alterations or repairs while the plant is operated from the other. This scheme produces considerable flexibility and insures a power supply to all feeders, at all times. Two sets of feeders are carried to each substation from the power plant, one feeder being connected to each set of bus-bars. Instrument transformers are located so that either the Philadelphia Electric Co. or the plant itself can meter all of the power supplied from either source.

In the substations, the high-tension bus structure with oil switches, disconnecting switches and instrument transformers are located on the same floor level with the switchboard. The high and low-tension switchboards are located on opposite sides of the room with the rotary converters on the floor between. The synchronous motor-driven air compressors are located in the same room, but a little apart from the switchboards. Fig. 12, shows one corner of one of the substations and Fig. 13 shows the other end of the room containing the synchronous motor-driven air compressors. The transformers are located in a separate compartment.

Owing to the value of the manufacturing space, it was not considered advisable to locate the substations at the center of gravity of the distributing system in the various buildings. This necessitated the use of dis-

FIG. 10—CONSTRUCTION DETAILS
Showing the metallic conduit.

tributing boards in connection with substation No. 3, one being located in machine shop No. 1, one in machine shop No. 2, and one in the erecting shop. Each one of these boards takes care of the distribution of the 440 volt, three-phase circuits and the 250 volt, direct-current circuits. The feeder circuits are carried from the board to the various parts of the buildings. The circuit breakers on these boards are equipped with alarm attachments which will insure the prompt reclosing of any circuit breakers that open due to overload or other trouble.

Substation No. 1 is located in the power plant and contains two 100 k.v.a., 6600-440 volt, single-phase transformers to supply the power plant and forge shop with power. These transformers are operated in open delta until the demand increases enough to require a third transformer. The substation may be used later to supply other nearby buildings with both alternating and direct-current power, in which case rotary converters will be installed.

Substation No. 2 is located at one end of the foundry and supplies current for power and light to the

foundry, pattern storage building and forge shop. The equipment of this sub-station consists of three 200 k.v.a., 6600-440 volt, single-phase transformers which supply three-phase power to operate machine tools, elevators, compressors and ventilating fans. Room has

FIG. 11 REACTANCE COIL CHAMBER

been provided for three additional transformers of the same capacity. Direct-current at 250 volts is furnished by two 300 kw, six-phase, 250 volt, rotary converters, which in turn receive their power from three-phase step-down transformers from 6600 volts to the converter voltage. Room has been provided for a third converter. This power is used to operate all cranes, variable speed blowers for the cupola furnaces and some variable speed machine tools in the pattern storage building.

A separate set of three 75 k.v.a., 6600-440 volt, single-phase transformers is installed for the lighting system. In addition to the regular lighting system, some special circuits are installed to furnish a limited amount of illumination for night service when the plant is closed down. Room has been provided for an additional set of lighting transformers.

FIG. 12 SUBSTATION SWITCHBOARD
With rotary converters and exciter in the foreground.

Ample illumination has been provided for the outside of the buildings by means of lamps mounted on the building walls. These lamps have been equipped with a special cutout so that the lamps can be lowered for cleaning and renewals.

Compressed air is furnished by two synchronous motor driven air compressors, one having a capacity of 1000 cu. ft. per minute, and the other having a capacity of 1500 cu. ft. per minute. Both compressors furnish air at 100 lbs. pressure. The synchronous motors are somewhat larger than necessary so that the extra capacity can be used for power-factor correction. The fields of the synchronous motors are wound for 250 volts excitation in order to utilize power from the rotary converters for this service. A small motor-generator set is furnished in addition as a reserve source of excitation.

The substations are well lighted and are fire proof and not directly connected to the main buildings. Entrance to the transformer room is obtained through a fire door. The transformer room of substation No. 2 is illustrated in Fig. 14. A cement coping around the floor prevents oil from flowing from the transformer room to other parts of the substation. All wiring between transformers, switchboards and machines is installed in underground fiber ducts.

Substation No. 3 is located at one end of machine shop No. 1, and supplies power and light for machine shops No. 1 and No. 2 and the erecting shop. The equipment in this substation consists of three 400 k.v.a.,

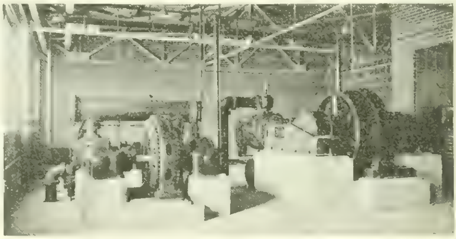


FIG. 13 CORNER OF SUBSTATION
Containing synchronous motor-driven air compressors.

6600-440 volt, single-phase transformers to supply power at 440 volts. Room has been provided for three additional transformers of the same capacity. Direct-current is furnished by three 300 kw, six-phase, 250 volt rotary converters. To take care of the lighting system, there are installed two 150 k.v.a., 6600-440 volt, single-phase transformers, and a third transformer will be added when the conditions warrant. Room for three additional transformers of the same capacity has been provided. The compressor equipment for this sub-station is a duplicate of that for No. 2 substation. As before stated, the main circuits from substation No. 3 are carried to three distributing boards, one located in each of the main buildings.

There are a total of 56 cranes located in the various buildings, all of which are equipped with direct-current motors operating at 250 volts. The larger cranes are equipped with two trolleys and each trolley is equipped with both main and auxiliary hoist. This type of crane requires seven controllers in the operating cage. Electric brakes are furnished on the shaft

of all hoist motors and also on the first countershaft of the main hoists. All cranes are equipped with a new type controller which uses cam type switches instead of the usual drum type or face plate controller. The hoist controllers are so arranged that graduated dynamic braking is used in lowering. The change has proven of great advantage, especially when handling ladles of molten metal in the foundry or assembling turbines on the erecting floor.

All cranes are equipped with a safety panel and each motor has its own contactor on the safety panel

FIG. 14—TRANSFORMER ROOM IN SUBSTATION NO. 2

controlled by an overload relay. After an overload relay has operated and the contactor opened, it cannot be closed again until the control handle has been brought to the off position. Each hoist is provided with a geared limit switch to prevent over-winding. All crane wiring is placed in metallic conduit. It is an interesting fact that women operators have been tried out on some of the smaller cranes and have proved very proficient.

For light trucking about the buildings and in the tunnels, electric trucks equipped with storage batteries have been installed and have proved very successful. For handling heavy castings and forgings between the foundry, machine shops and forge shop, and between the machine shops and the storage yard, four ten-ton burden bearing storage battery locomotives with four trailers have been installed. These trucks are of particularly heavy and rugged design, and will carry a maximum load of 50 tons each. In order to reduce the height of platform, it was necessary to supply roller bearings on the main axles. The batteries on these locomotives are charged by simply plugging into the 250 volt circuit at convenient points. Owing to the fact that the smaller trucks have a fewer number of batteries, it would not be economical to charge them di-

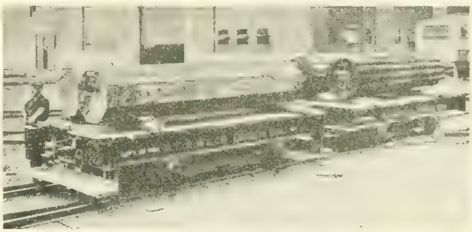


FIG. 15—FIFTY TON STORAGE BATTERY TRUCKS WITH TRAILERS

rectly from the 250 volt circuit, as too much power would be lost in resistance. For this reason, separate motor-generator sets are provided for charging the batteries of the small trucks, one located on the surface and the other in the tunnel.

It is possible that the substations will be tied together in such a manner that one can be used to supply all buildings during times when only small portions of the works are in operation. The entire plant has been laid out with the object in view of producing power at the least possible expense with the greatest possible flexibility and safety, and at the same time taking care of any possible future expansion.

What Are Safe Operating Temperatures for Mica Insulation

H. D. Stephens
Power Department,
Westinghouse Electric & Mfg. Co.

THIS QUESTION has perplexed manufacturer and operator alike for a number or years. In the search for a thoroughly acceptable answer, a great deal of time and money have been devoted to extensive study and research. We know that electric heating elements, with operating temperatures of five hundred to six hundred degrees are perfectly satisfactory. But the burning out of a heating element entails relatively little inconvenience and expense. Such temperatures are essential to efficiency, and mica is the best known and most acceptable insulating material for such service.

It is known that generators with measured temperatures of only seventy and eighty degrees C. have failed, and that the evidence of temperature deterioration has been strong. Even admitting a possible error of more than one hundred percent, due to methods of measurements, the discrepancy between heating element and generator performance is enormous. Based on experience neither operator nor manufacturer could consider maximum temperatures of three and four hundred degrees safe. And such values are not necessary, and not economical in the generator.

But with the mass of indisputable evidence

gathered, it is known that temperatures considerably above one hundred degrees exist in the wide core, high speed and large capacity machines of today, and that such units have very satisfactory operating records. In determining the maximum safe operating temperatures for their mica insulated armature coils, two methods of observation and research have been followed:

1—Based on laboratory tests, where conditions approximate those found in actual practice, and

2—Based on the actual performance of the generators in service.

One of the so-called laboratory tests from which valuable information was gathered was made by outside operating engineers using a standard 6600 volt, machine-wrapped, mica-insulated coil. The straight sides of this coil were clamped, heavily lagged with felt and tape, exploring coils and thermometers being located underneath in contact with the coil, and alternating current, sufficient to heat the coil to the temperatures wanted, was circulated through the coil. The results are given in Table 1. In marked contrast to the characteristics of treated tape insulations, no appreciable increase in dielectric loss or leakage was noted at these temperatures.

TABLE I—TEST DATA.

Temperature Degrees C.	Hours	Insulation Test
125	81	6600 volts continuous
150	100	6600 volts continuous
150	102	10 000 volts for one minute once an hour.
150	48	15 000 volts for one minute every 12 hours —for 10 minutes at end of test.

To test this characteristic further one side of the coil was then wrapped with asbestos tape, soaked with water, and left on for six hours. At 15 000 volts no material increase in leakage could be noted.

Lastly the coil was tested to break down. The wet side broke down at 23 500 volts, and the dry side at 30 000 volts at one point, 35 000 volts at another and 42 500 volts at still another. The tape insulation on the ends at 40 500 volts. A careful examination of the coil also disclosed no visible evidences of temperature deterioration.

To check the outside findings, a similar coil was then tested at the factory, first for 150 hours at 150 degrees C, and then for 150 hours more at 220 degrees. No appreciable evidences of temperature deterioration were discovered, and even at 220 degrees the "dielectric loss" was not large enough to be of consequence.

Another instructive laboratory test, that more closely parallels the conditions existing in a generator, was made by building a model with coils, punchings, ventilating slots, and air-gap section of typical proportions. A solid cap set above the punchings with small clearance gave normal fluxes when current was circulated through the coil. The model was enclosed, and a fan attached gave cooling air in the volume and pressure required. Both thermocouples and resistance coils were built in at the points where temperature readings were desired. Resistance coils four inches in length were used, and the couples were the same as used for regular generator detectors. A couple embedded in the punchings showed a rise of 58 degrees C. another couple each 78.5 degrees when placed between two coils and, directly above a resistance coil which showed 74.5 degrees. A third couple actually placed inside the resistance coil read 76 degrees. A single paper cell surrounded both coils in this slot. In exactly the same locations in a second slot, and with a separate paper cell around each coil so that couples and resistance coil were outside of the cells, the couple above the resistance coil read only 48 degrees, the resistance coil 49 degrees and the couple inside the resistance coil 51.5 degrees. This test is particularly valuable as disproving a somewhat common fallacy that almost any type of detector, located at almost any inaccessible point in a generator stator, shows approximately "hot spot" temperatures. It demonstrates the necessity for a proper type and location of detector, if dependable readings are to be obtained.

FIG. 1—PARTIALLY DISMANTLED THERMOCOUPLE

Showing its ruggedness. The temperature reading obtained is that due to the temperature at the junction point between the two metals used.

Of even more practical value than the data obtained in laboratory research, is that obtained from actual operation. One of the most conclusive evidences of the ability of mica to withstand high temperatures is found in the performance of some Westinghouse generators installed at Niagra Falls. These were built in 1895, and in 1913 an opportunity was given to install thermocouples in one of these machines. In the Niagara tests temperatures of the copper in the center of the core were obtained in a mica insulated generator that has been in operation for about twenty years. Thermocouples were installed in contact with the copper and in various other locations within the slots. Internal temperatures were obtained for the range of loads through which the generator normally operates. From the operating record the length of time for various loads (above the average) was also obtained and from these records and the measured temperatures the length of time the generator has operated at different temperatures was found to be as follows:—

Length of Service in Hours	Range of Operating Temperature (Based on 35 degree air)
40 000	120 to 145 degrees C.
13 000	145 to 175 degrees C.
8 200	175 to 210 degrees C.
2 600	210 to 245 degrees C.
100	245 to 285 degrees C.

The insulation used in this generator was a hand-wrapped mica wrapper substantially as used in many generators today. The operating record shown by the above figures means that this generator has been running for over 60 000 hours (equivalent to nearly seven years continuous service or to ten years service of 16 hours per day) at temperatures from 120 to 285 degrees C.; it has operated for a time equivalent to nearly three years without shutdown at temperatures above 145 degrees and it has operated for 10 900 hours, equivalent to fifteen months continuous operation at temperatures above 175 degrees.

Additional data on actual internal temperatures of generators of large capacity has been steadily collected

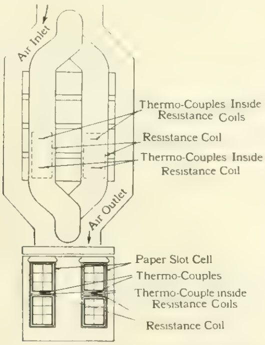


FIG. 2—CROSS-SECTIONS OF MODEL COIL

ever since the availability of the embedded detector for this application was discovered. In general, modern machines are actually cooler inside than many of earlier design, for armature coil conductors are better sectionalized, eddy current losses are reduced and more adequate and uniform ventilation is now provided. Internal "hot spot" temperatures varying between 100 and 150 degrees have been expected and found to be the actual operating temperatures at rated outputs. Mica has been the basic insulating material employed, and excellent operating records have been experienced.

Since 1912 thermocouples have been installed in practically every large generator of new design and readings obtained of internal hot spot temperatures. (In special cases as many as thirty couples have been installed in a single generator). These tests have been made by the zero power-factor method of loading, the generator really operating as a synchronous motor or condenser, with normal coil, load and armature copper loses, and with field copper losses higher than when in actual operation as a generator at higher power-factors. The Westinghouse Company has installed as part of its regulator testing equipment a generator of 6000 k.v.a. and another of 5000 k.v.a. for supplying load for such tests and by making use of generators on the test floor a number of zero power factor tests between 12 000 k.v.a. and 18 000 k.v.a. have been conducted. This comprehensive testing policy has resulted in the accumulation of a mass of data on hot spot temperatures covering all types and sizes of units. The general result has been to modify preconceived ideas of generator temperatures considerably. It was not realized before this data was available that temperature drops in generators were so large. In many cases generators that were designed in line with past practice to meet a 50 degree rise by thermometer were found to have hot spot temperatures 50 degrees higher than the surface temperature. The reasons for these large temperature differences have been discussed in various papers before the engineering societies; the general results of tests only need be given here.

Tests on twelve 60 cycle turbogenerators ranging in size from 5000 to 20 000 k.v.a. gave average results as follows:—

Surface coil temperature rises, by thermometer, 22 degrees C.

Average coil temperature rise, by resistance, 43 degrees C.

Hot spot coil temperature rise, by thermo-couple, 85 degrees C.

Similar tests on nine large 60 cycle moderate speed generators (mainly waterwheel driven) gave the following average temperature rises:—

Surface coil temperature rise by thermometer, 45 degrees C.

Average coil temperature rise by resistance, 54 degrees C.

Hot spot coil temperature rise by thermo-couple, 82 degrees C.

From the accumulation of evidence gathered, it is certain,—

1—That large generators, insulated with the best and latest types of mica insulation, not only can but actually do operate with safety with total internal temperatures up to at least 150 degrees C.

2—That the results obtained by the use of embedded temperature detectors vary widely, and that the manufacturer who is carefully and generally testing with such equipment, is best fitted to locate and to specify the type of measuring devices to be employed.

Lastly, it would seem equally certain, assuming that embedded detector readings are to be made the basis of contract guarantees, that the prospective purchaser should heartily sanction a form of guarantee which tends to encourage, rather than discourage, the manufacturer from choosing a type of detector and locating it where maximum temperature readings are obtainable.

Characteristics of Starting and Lighting Batteries of the Lead Acid Type

O. W. A. Oetting,
Special Engineer,
Willard Storage Battery Company

The application of the electric motor for starting internal combustion engines during the past few years has developed a new branch in the electrical industry. Electric starting motors are now applied almost universally to all automobiles. The conveniences of this method of starting and the insurance against cranking accidents will lead, no doubt, to a wider adoption of this system for truck service. The latest development in this industry has been the application of starting and lighting systems to farm tractors.

The starting of internal combustion engines by an electric motor is feasible because of the possibility of storing energy in batteries at a low rate of current by means of a small generator. This stored energy is available then for short intervals of time at very high rates of current.

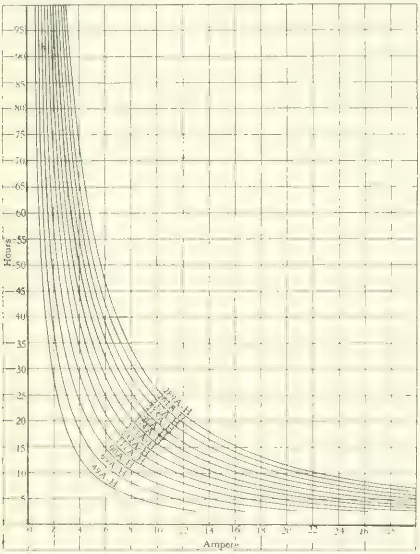


FIG. 1—TIME REQUIRED TO DISCHARGE AUTOMOTIVE TYPE OF BATTERIES

At low rates of current to 1.8 volts per cell at 80 degrees F.

The application of the electric motor for starting internal combustion engines brought about a demand for much higher discharge rates of current from the storage batteries than had previously been considered feasible. Formerly, discharge rates of one hour's duration were often used for rating storage batteries. With the advent of the electric starter, batteries were given ratings of discharge for a period of twenty minutes, and later on, voltage tests were called for at rates of current four and five times the twenty minute rate. These high rates of current had to be secured from a battery of minimum size and weight.

DISCHARGE RATES

It is a well known fact that the capacity of a storage battery is a function of the rate of current at which it is discharged. The performance of various sizes of automotive batteries at low rates of discharge is shown by the curves in Fig. 1. The rating of the battery indicated on these curves is the ampere hour capacity at the five ampere rate of current, as standardized* in the following rule: *"Batteries for combined lighting and starting service shall have two ratings, of which the first shall indicate the lighting ability and be the capacity in ampere hours of the battery when discharged continuously at a five ampere rate to a final voltage of 1.8 per cell, the temperature of the battery beginning such discharge being 80 degrees F."*

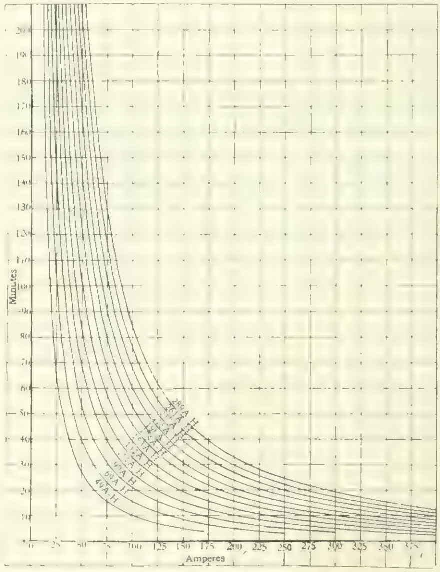


FIG. 2—TIME REQUIRED TO DISCHARGE AUTOMOTIVE TYPES OF BATTERIES

At high rates of current to 1.5 volts per cell at 80 degrees F.

The starting characteristics of a battery are determined by higher rates of current than those given in the curves shown in Fig. 1. A battery with an ampere hour capacity that is satisfactory for starting at

*By the Society of Automotive Engineers.

low temperatures usually will be found to be of sufficient size to supply the remainder of the electrical system, such as lights, ignition, etc. When selecting the size of a starting battery, the requirements of the electrical system under the severest starting conditions should be known. Fig. 2 shows the time required to discharge different sizes of automotive batteries at high rates of current. Automotive batteries for starting purposes have a standard rating as stated in the latter

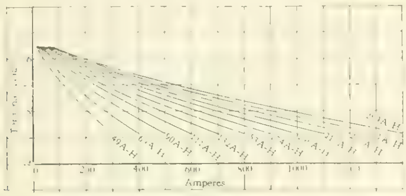


FIG. 3—FIVE-SECOND VOLTAGE CURVES OF AUTOMOBILE TYPES OF BATTERIES

At high rates of discharge at 80 degrees F.

part of the standard rule:— *"The second rating shall indicate starting ability and shall be the rate in amperes at which the battery will discharge for 20 minutes continuously to a final voltage of not less than 1.65 per cell. The temperature of the battery beginning such discharge to be 80 degrees F."*

CRANKING VOLTAGES

The current required from a battery to roll the engine under normal conditions varies from the 10 to the 20 minute rate of discharge. If the engine is stiff or the temperature is low, this rate of current is increased considerably. The voltages that are available

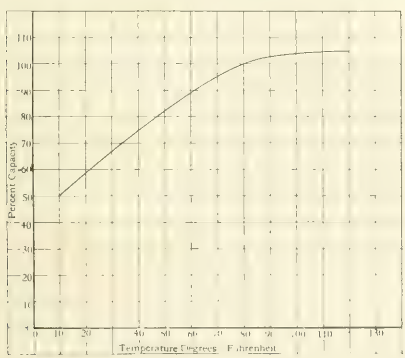


FIG. 4—VARIATION OF CAPACITY OF BATTERY WITH TEMPERATURE

for cranking an engine under normal temperature conditions are given for the various sizes of batteries in Fig. 3. These curves show the voltage that a battery will give at the end of five seconds at a certain discharge rate of current. Curves such as these should be used in the design of starting motors and also in the selection of the size of battery for the starting system.

TEMPERATURE CHARACTERISTICS

The effect of temperature on the capacity of a lead acid type of battery is shown in Fig. 4. It will be seen from this curve that a battery has only half the capacity at a temperature of 10 degrees F. that it has at normal temperatures. The voltage also is lower, as

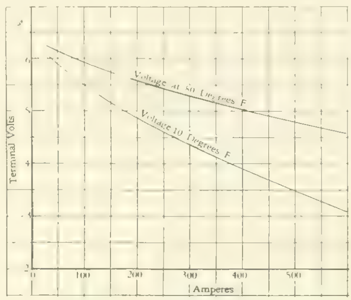


FIG. 5—COMPARISON OF VOLTAGE CHARACTERISTICS OF 111 AMPERE-HOUR BATTERY

At 80 degrees F. and 10 degrees F.

shown in Fig. 5, which gives the comparison of the five second voltages of a battery at 80 and at 10 degrees F.

Low temperatures have no detrimental effect on a battery if the electrolyte does not freeze. The freezing point of the electrolyte varies with the state of charge in the battery, as shown in Fig. 6. The necessity of keeping the battery charged above a specific gravity of 1.250 during extreme cold weather conditions is apparent from this curve. High temperatures have the effect of increasing the capacity of a battery, but are detrimental in that they decrease the life of the battery.

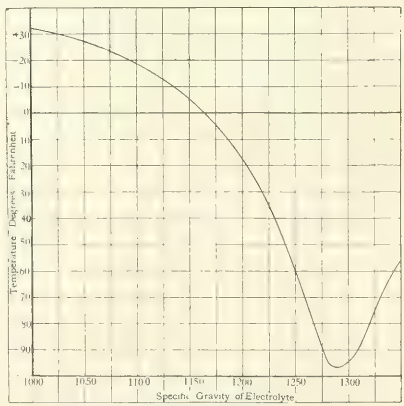


FIG. 6—FREEZING POINTS OF SULPHURIC ACID ELECTROLYTE

At various densities.

Effect of Low Temperatures on Starting—The difficulty encountered in starting an engine during the winter months is a result not of one, but of several conditions. All of these conditions must be taken into consideration in the design of the engine and its various accessories. The effects of low temperatures on the battery have been pointed out. Fig. 7 shows the five

second voltages of automobile batteries at a temperature of 10 degrees F. This does not represent the extreme temperature at which the batteries are required to operate, but was chosen as a standard to represent the average temperature for the country during the three winter months. In addition to the effects on the

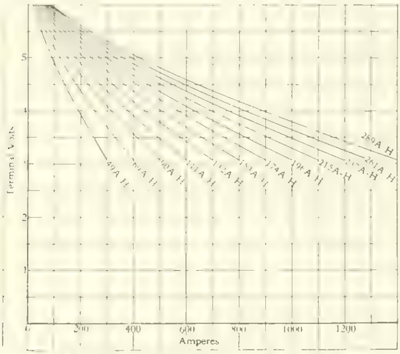


FIG. 7—FIVE-SECOND VOLTAGE CURVES OF AUTOMOTIVE TYPES
Of batteries at high rates of discharge at 10 degrees F.

battery, the lubricant of an engine at these low temperatures has a greater viscosity, thereby requiring more power to break away and turn the engine. Then again, it is more difficult to vaporize the fuel if the engine is cold, especially if the grade of fuel is not of the best quality or the carbureter adjustment is not adapted for this quality of fuel.

Within the past few years, tests have been made on various automobile engines by placing them in a refrigerator to approximate cold weather conditions. During these tests, the engine, starter, and the storage battery were placed within the cooling chamber and the temperature lowered the desired amount. The power required to start the engine at various temperatures was determined as indicated in Fig. 8.* A table of battery sizes in terms of the piston displacements of the engine was suggested for six volt starting systems having a gear reduction between the starter and the engine ap-

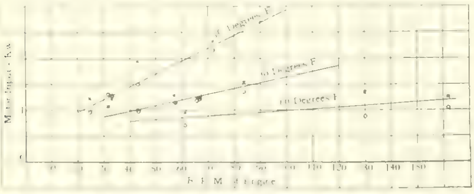


FIG. 8—[illegible] REQUIRED TO START A FOUR CYLINDER ENGINE OF 171 CUBIC INCHES DISPLACEMENT

o Power required to roll engine.
x Power required for breakaway.

proximately equal to 10 to 1. These battery sizes are indicated in Fig. 9 by the dotted lines. The circles in this illustration were the batteries in use on automobiles as published in a list of the various cars at the time these tests were summarized. It is apparent as a result of these investigations that a more consistent selection of battery sizes is necessary.

An attempt was recently made to give a general expression of the battery size for any starting system on passenger cars or motor trucks. The empirical formula given below has been found to be satisfactory

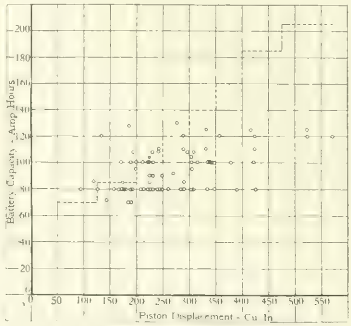


FIG. 9—BATTERY SIZES RECOMMENDED FOR VARIOUS SIZE ENGINES

for systems where the starting motor is a single unit and is applied to start the engine by meshing a pinion with the teeth cut in the flywheel of the engine. The size of battery expressed in this formula is stated only for average temperature conditions at 10 degrees F.

$$AH = \frac{20\ D + 2000}{V\ R}$$

where

AH = Ampere hour capacity of battery at five ampere rate at 80 degrees F.
D = Piston displacement of engine in cubic inches.
V = Voltage of the starting system.
R = Total gear reduction between the starter and the engine.

This relation is purely empirical, as the variables are too numerous to calculate the proper size of battery for satisfactory starting at low temperatures. As there is a wide divergence in the design and manufacture of the various automotive engines, each application should be tested separately to determine the power that is re-

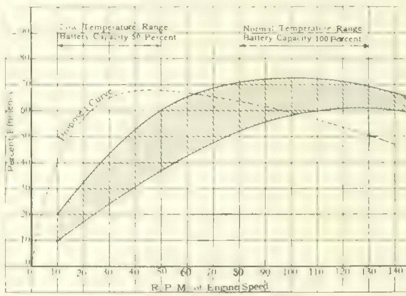


FIG. 10—EFFICIENCIES OF STARTING SYSTEMS
Starter reduction 12 to 1.

quired to start the engine under cold weather conditions. In the absence of such data, the formula given above may be used in a tentative determination of battery size for a new installation.

A change in the efficiency curve of starting motors was suggested at the time that the tests previously

*A summary of these tests was published in the Journal of the Society of Automotive Engineers, February 1918.

mentioned were published. This suggestion was to change the characteristics of the efficiency curve of the starting motor so as to increase the total efficiency of the starting system for cold weather conditions. Fig. 10 shows the range of efficiencies of various sizes of starting motors. These efficiencies were taken from curves of various starting motors, and a gear ratio of 12 to 1 between the motor and the engine was assumed for this illustration.

The maximum efficiency of the average of these curves is obtained at about 115 r.p.m. of the engine. In the investigations on the characteristics of the starting systems at low temperatures, the range of cranking speeds for temperatures at or below 10 degrees F. lay between 10 and 50 r.p.m. Therefore, an increase of the starting motor efficiency in this range would improve the performance of the whole starting system at low temperatures when the maximum efficiency is most essential. The proposed curve, shown in Fig. 10, shows much higher efficiencies from 10 to 50 r.p.m., the speeds

TABLE I—TEMPERATURE RISE OF BATTERIES

Miles Run	Ampere-Hour Capacity of Battery	Temperature at End of Run Degrees F.	Temperature Rise Degrees F.
62	155	116	26
40	86	114	24
61	90	110	20
58	35	101	11
180	86	122	32
50	106	114	24
70	90	108	18
75	106	128	38
120	110	102	12
			Average 23

encountered at low temperatures, a condition under which the battery capacity is reduced about 50 percent. The cranking speeds at normal temperatures necessarily will be reduced, but still will be higher than those secured at low temperatures when all the conditions are much less favorable for starting. The increase in battery capacity at normal temperatures will more than offset this decrease in the starting motor efficiency. The result of this change would be a more uniform efficiency curve for the whole starting system throughout the entire range of cranking speeds and temperature variations.

The suggested change can be made by increasing the gear reduction between the engine and the starting motor—perhaps, by an intermediate reduction of 1.5 or 2 to 1—or possibly a change in the design of the starter itself will accomplish this result. If a double gear reduction is used, the design of the starting motor must be made so that the armature has an acceleration that does not allow the starting pinion to fall out of mesh with the teeth on the flywheel.

CHARGING

Excessive charging overheats a battery and is detrimental because it loosens the active materials from the framework of the plate and also chars the insulation between the plates, when wood separators are used for this purpose. Fig. 11 shows the heating curves of batteries tested in a laboratory at various rates of current. It will be noticed that all the rates, except the lowest, cause the temperatures to rise above 110 degrees F. in less than six hours time. A slightly higher charging rate than the minimum current shown in this figure may be used to charge a battery on a car, because the temperature is lowered somewhat by the agitation of the electrolyte in the battery when the car is in motion. Charging rates much in excess of this minimum, however, will overheat the battery, especially when the car is on a long tour. The table in Fig. 11 also gives the start and finish rates of current for charging any size of battery when it has become discharged.

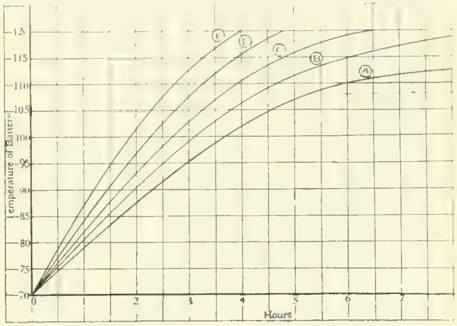


FIG. 11—TEMPERATURE RISE OF AUTOMOTIVE BATTERIES

While overcharging at various rates.

CHARGING RATES

Battery Size Ampere-Hours	A	B	C	D	E	Name Plate Rating Start	Name Plate Rating Finish
49	5.2	5.7	6.4	7.2	8.3	8.0	2.5
69	6.9	7.6	8.5	9.6	11.1	10.0	3.5
90	8.5	9.4	10.5	11.9	13.8	13.0	4.5
111	10.1	11.3	12.6	14.4	16.7	15.5	5.0
132	12.0	13.2	14.8	16.8	19.4	18.0	6.0
153	13.7	15.1	16.8	19.2	22.2	20.5	7.0
174	15.4	17.0	19.0	21.6	25.0	23.0	7.5
196	17.1	18.9	21.1	24.0	27.8	26.0	8.5
215	18.8	20.8	23.2	26.3	30.5	28.0	9.5
237	20.6	22.7	25.4	28.7	33.3	30.5	10.0
261	22.2	24.5	27.4	31.1	36.1	33.0	11.0
289	24.8	26.4	29.5	33.5	38.9	35.5	12.0

The temperatures of batteries on nine different cars at the end of a run made in Cleveland, Ohio, during the month of July are given in Table 1. The mean temperature of the day on which these results were taken was 90 degrees F. The average temperature for the three summer months in the southern part of this country is several degrees higher than 90 degrees F. An increase of 23 degrees F., the average temperature rise of the batteries in these tests, over the air temperature in these localities will result in temperatures in excess of 110 degrees F. for the battery. The necessity of charging the battery at as low a rate as possible is apparent from these results.

All batteries should be kept as nearly fully charged as possible, but the rate of charge must not be excessive. Some cars are used for long hauls where very few starts are required. Others are used at times, especially in the winter, when the demand for lights and

frequent starts is above the average, and when daylight driving, the time the battery charge can be restored, is at a minimum. A physician's car is required to make many starts, but the interval of time for charging the battery between these starts is comparatively small. The problem of determining the proper rate of charge for automobile batteries is a difficult one. A charging rate that will be satisfactory for a short-haul many-stop car will overcharge a battery on a long-haul, few-stop tour.

Sometime ago, the characteristic curve shown in Fig. 12 was suggested for the generating systems that supplied the charge to the storage battery. In cases where this characteristic curve was adopted, the results

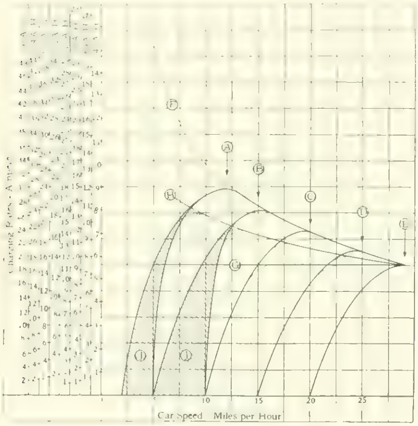


FIG. 12—CURVES OF GENERATOR OUTPUT FOR CHARGING STORAGE BATTERIES AT VARIOUS CAR SPEEDS

Curves represent actual current input to battery when the generator is hot. If battery ignition is used, the generator must produce this extra current. *a*—Best generator; *b*—Satisfactory; *c*—Fair; *d*—Dangerous; *e*—Impractical; *f*—Must not be exceeded continuously at any point or overheating in summer will occur; *g*—Highest point for generators with straight output curves; *h*—Curve for generator with a slightly sloping characteristic; *j*—Cutting in allowance for a and b.

have been found to be more satisfactory than those of a system where a rising characteristic is used or where the charging current is constant for all car speeds. The short-haul, many-stop driver usually travels from 12 to 18 miles per hour and the charging rates for these car speeds, as shown in Fig. 12, keeps the battery fully charged. On the other hand, the driver making few starts and touring 30 or more miles per hour does not overheat his battery at these rates of current. Any type of regulation—third brush, bucking series field, thermostatic control, potential regulator, etc.,—that is used to vary the generator current as the speed of the car changes, should be satisfactory for charging the storage battery if the curve and values of current shown in Fig. 12 are delivered to the battery under normal operating conditions.

INSTALLATION

One of the most important considerations for the location of a storage battery is that it be accessible for inspection. If this point is not considered, the battery probably will not receive the proper attention. A strong, rigid mounting on the frame of the automobile underneath either the front seat or the floor boards of the car has been found to be a satisfactory location for the battery. The running board is used sometimes for this purpose, especially on motor trucks, and from a standpoint of accessibility, this probably is the best location for the battery. The vibration, however, in this place is much more severe than if the battery were underhung from the frame or placed underneath the seat. On the running board, too, it is subjected to other abuses and should, therefore, be enclosed for protection in a strong metal box, which can be opened readily.

The battery leads should be sufficiently long so that there is no pull on any of the battery parts. If no allowance is made for extra length of battery connections, the wires will pull on the battery terminals, when the car is in motion, and the battery will be damaged.

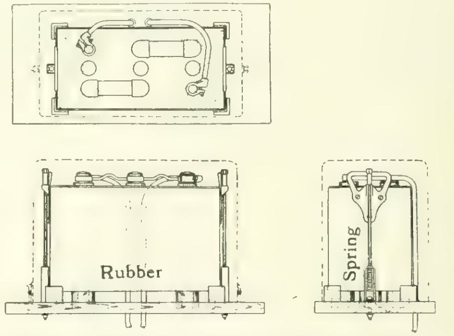


FIG. 13—METHOD OF MOUNTING A BATTERY ON TRUCKS

A storage battery used on a truck or tractor should be installed preferably on a more flexible mounting than that commonly employed on automobiles. Spring suspensions have been used for mounting storage batteries in such cases. A type of mounting of more recent origin, which has been found to be superior to the spring type of mounting, is shown in Fig. 13. The battery is placed on cylindrical, rubber cushions and each hold-down member over the handles of the battery contains a small helical spring to take the slight rebound of the battery. A sheet metal cover that can be removed easily completes the installation and gives the battery the proper protection. The life of a battery that is installed in this manner should be increased considerably over the life of one mounted rigidly.

RECENT DEVELOPMENTS

One of the latest developments in the storage battery art has been the use of threaded rubber insulation in place of wooden separators in starting and lighting batteries. Service records show that the average life of a wood insulated starting and lighting battery varies from 18 to 24 months. In most cases, it has been necessary to re-insulate the battery with new separators

in order to obtain this life. The action of heat on the wood separator causes it to carbonize, so that the separator ceases to be a perfect insulator and also becomes weak mechanically. A perforated sheet of hard rubber is sometimes used to supplement the wood separator. The effect of this double insulation, however, is a decrease in the voltage that is available for starting the engine, as shown by the curves in Fig. 14. This effect at low temperatures is even more marked than at 70 degrees F.

The threaded rubber insulator obviates the necessity of using a double insulation between the plates of the battery. The structure of this insulation is hard rubber, which is perforated with thousands of minute holes, each hole containing a tiny thread which prevents the passage of the active materials from one plate to the other, and also aids the diffusion of the acid, in that it acts like a wick in the acid. The voltage of a battery using threaded rubber insulation is slightly greater than that obtained from the same type of battery using wood separators.

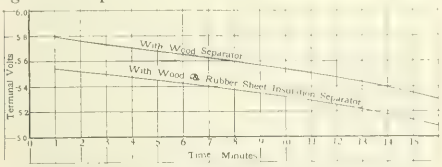


FIG. 14—COMPARISON OF BATTERY WITH WOOD SEPARATORS

With one using both wood and hard rubber sheets as insulation at a discharge rate of 170 amperes, 70 degrees F.

One of the common causes of battery failure is overheating. This overheating buckles the plates of the battery, weakens the wood separators, and, in time, causes the corners or the edges of the plates to wear through the wood and short-circuit the battery element. In the manufacture of a threaded rubber insulator, a thick hard rubber rib is attached to each edge of the insulator. This re-enforcement of solid rubber will lengthen the life of a battery considerably.

Within the past two years, a more rugged type of storage battery has been developed and built for truck and tractor service. This type of battery was first used on Class *B* and other government trucks that were used for transport service during the war. In the manufacture of this battery, extra heavy plates 11-64 inch in thickness are used and are insulated with heavy threaded rubber insulators. The thickness of the hard rubber jars used in this type of battery is increased 50 percent over that used in the automobile type of battery, and the material used in their manufacture is required to meet rigid specifications of tensile strength and percentage of elongation. The case containing the cells is made of extra heavy hardwood, the sides being fastened together by means of two long bolts between the cells. The five second voltages of the various sizes of this type of battery at 10 degrees F. are shown in Fig. 15.

In the development of this type of battery, a vibrating platform was used to approximate the severest service conditions. The battery was fastened to this platform rigidly without the use of rubber cushions or spring suspensions. A four point cam was arranged to drop this platform on a solid anvil at a speed of 560 vibrations per minute. In a test of 30 hours duration, the battery was subjected to approximately one million vibrations. It was necesary for the battery to with-

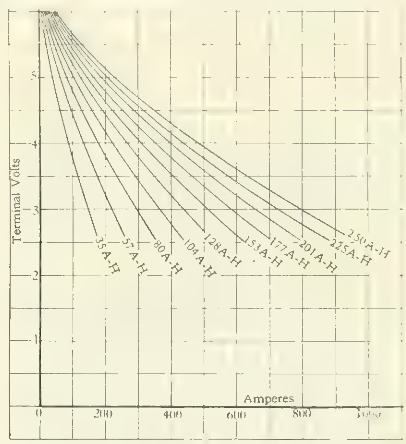


FIG. 15—FIVE-SECOND VOLTAGE CURVES

Of heavy duty types of truck and tractor batteries at high rates of discharge at 10 degrees F.

stand this test without any failure before the final construction was approved as satisfactory for the service for which it was desired.

No improvement in the construction of a storage battery can be made that will be a "cure-all" for its inability to function properly if the battery is not given the proper care. A storage battery is electro-chemical in its action and a few simple rules in regard to the care of a battery must be observed in order to have the battery give satisfactory service. If these directions, as stated by the storage battery manufacturer, are followed carefully, an appreciable time will be added to the life of a battery in service.

A High-Frequency Generator
For Airplane Wireless Telegraph Sets

A. Nyman

IN THE latter part of 1917 the Signal Corps of the United States Army undertook the development of a wireless telegraph spark set for use on observation airplanes for controlling artillery fire. The main requirements of the set are lightness, compactness and reliability. The scheme finally adopted, consisted of the following parts:—

1—A 900 cycle generator driven by a constant speed propeller and mounted on the landing gear of the airplane.
2—A 900 cycle transformer charging a condenser to a pressure from 7500 to 15 000 volts.
3—A high-frequency oscillation circuit, consisting of the above condenser, a synchronous rotary spark disc mounted on the shaft of the generator, an oscillation transformer, a loading coil (or variometer) and the antenna.

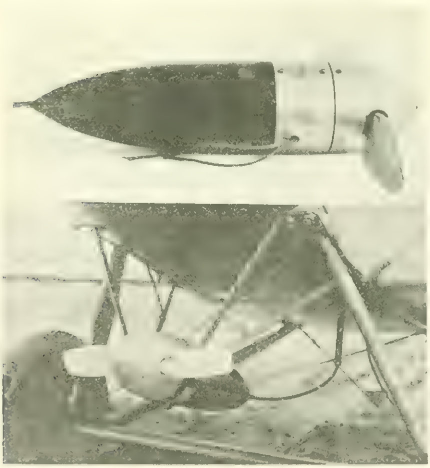


FIG. 1—WIND DRIVEN RADIO GENERATOR SET

Mounted on the landing gear of an airplane. The regulating air fan is equipped with a centrifugal governor which changes the pitch of the blades to produce approximately constant generator speed, regardless of the air speed.

Of these parts only the variometer and the antenna were mounted in the body or fuselage. All the other parts were mounted on the landing gear. Auxiliary parts were assembled within a stream line cover and attached to the rear end of the generator. This stream line cover was moulded out of micarta duck in preference to metal on account of the high frequency oscillations taking place inside. The generators, rotary spark gaps and the micarta tail covers were manufactured by the Westinghouse Electric & Mfg. Company. The remaining parts and the final assembly were completed by the International Radio Telegraph Company. The sets were mounted on the planes by the Air Service.

A large number of these sets have been built and put into service. Manufacturing facilities for large scale production were developed, and extensive tests were carried out, both in the shop and in the field to secure the best product and the best operation. A range of 50 to 100 miles is generally possible with this set. Another set has been built with a range up to 150 miles, and a set for still longer range has been contemplated. This article deals chiefly with the design of the generator and the operation of the power supply circuits.

CONSTRUCTION

The construction of the generator is shown in Figs. 3 to 6. Two aluminum brackets enclose a narrow iron frame (stator) built up of punchings of especially thin sheet steel (0.004 to 0.005 in.). This thin sheet steel is used in order to reduce the iron loss in the parts of the circuit carrying high frequency magnetic flux. Similar steel is used for the rotor punchings.

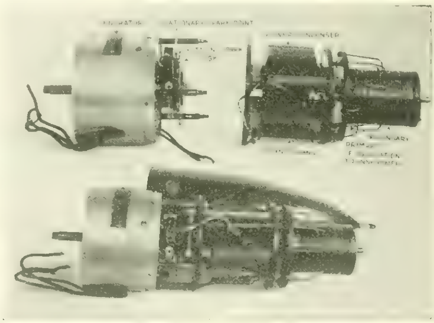


FIG. 2—DETAIL VIEWS OF RADIO TRANSMITTER PARTS

The rotor is supported on ball bearings, front and rear, and carries a small commutator. Four brushes, in aluminum brushholders, are mounted permanently in the rear or commutator bracket. Access to the brushes is gained through openings in the front of the bracket covered normally with an aluminum ring.

The method of assembly and holding the stator and rotor punchings is noteworthy. The rotor punchings have one micarta punching on each side and are held securely between two steel washers. A similar construction could not be conveniently applied to the stator punchings, but fibre punchings placed on the ends are held together by six copper rivets, and six brass studs hold the punchings to the rear or commutator bracket. The front bracket is then attached by means of screws to the above studs. Some difficulty was experienced in keeping the punchings flat. The small air-gap (0.010 inch) would be completely closed up on tightening the punchings to the bracket. A special expanding mould and pressing tools were used to avoid this difficulty.

With the self-excited inductor type design used, the length of the air-gap played a great part in determining the voltage output of the machine. The air-gap had to be held within narrow limits. Great care was also exercised in centering the stator and the ball bearing seats in order to give a uniform gap all around. In passing the machine through tests, a voltage range on individual machines of five volts above and below the normal at 4500 r.p.m. was secured without adjustment; i.e. by manufacturing accuracy only.

The rotor winding fills only a very small portion of the rotor slot. This winding has to carry only the small exciting current. The stator windings consist of a continuous alternating-current winding embracing the individual teeth on the stator. This is hand wound. A field winding of four coils is placed around each group of four teeth. These coils are machine wound and forced into place in a special fixture designed not to distort the rather flexible iron frame. They are held securely by fibre wedges.

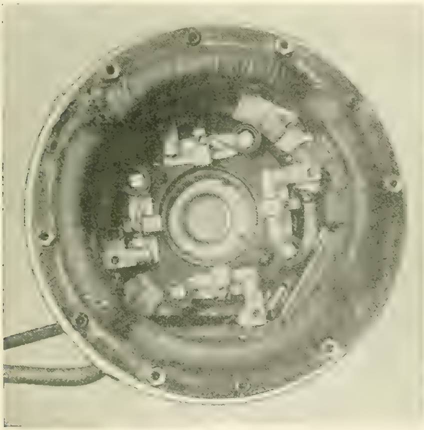


FIG. 3—STATOR PARTS OF SELF-EXCITED INDUCTOR GENERATOR
Showing the stator mounted in the rear bracket; the field coils and the high frequency winding; also the brush mounting and the protective condenser.

The micarta duck tail piece is a unique product of its kind. The wall is only one-sixteenth inch thick, yet its strength is not sacrificed to its lightness. Treated duck is cut to conform to the final shape, stitched together and molded. The mold required extremely fine machining. Uniform thickness must be obtained while its surface must conform to a stream line design. The outside mold consists of three sections. The inside mold is one piece.

The protective condenser, Fig. 2, is made of impregnated paper and tinfoil embedded in micarta compound. Terminals are formed by molded-in metal inserts. The condenser serves to protect the winding from excessive high voltage and high frequency surges.

The rotary spark disc consists of a brass disc molded on a bushing. Its rim carries a number of spark points (24, 12 etc.) which determine the number of sparks per revolution. Much attention was given to secure close limits in axial and radial dimensions, careful machining and molding being essential.

The manufacture of both the generator and the various parts gave rise to a number of problems of production. The problems confronted had to be faced and solved in an extremely short time. The success attained was largely due to the close co-operation and the unlimited manufacturing facilities offered by a large industrial establishment.

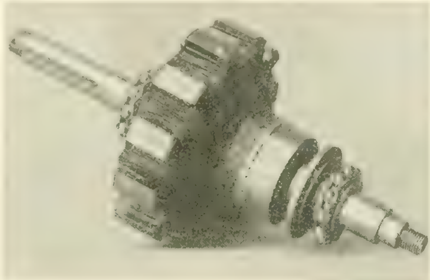


FIG. 4—ROTOR OF SELF-EXCITED INDUCTOR TYPE ALTERNATOR
Showing the wide open slots, the teeth acting as inductors and the small direct current winding in the bottom of the slots connected to the commutator.

THEORY OF OPERATION OF GENERATOR

The stator and rotor punchings and the windings on them are shown diagramatically in Fig. 7. The stator consists of four groups of four teeth each. The teeth are spaced one twenty-fourth of the circumference apart; two teeth being omitted between each group. Each group constitutes a stationary magnetic pole, and carries an encircling field winding to which direct current is supplied from the rotor. The rotor is wound as a four-pole direct current armature to supply current for the above field winding. High frequency alternating-current is excited in a separate winding. This winding consists of coils encircling individual stator teeth and connected in series as described below.

The twelve teeth of the rotor have a pitch just double that of the stator teeth and the slots in between are very wide, the opening being greater than the stator pitch. For a certain position of the rotor, as shown in Fig. 7, one-half of the stator teeth oppose the rotor teeth, and the other half oppose the rotor slots. Fig. 8 illustrates the motion of the magnetic flux as the rotor travels the length of one rotor tooth pitch. Each half,

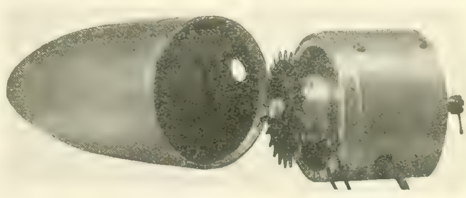


FIG. 5—GENERATOR ASSEMBLED
With spark gap disc mounted on shaft and tail cover removed.

A and *B*, of the flux follows its individual rotor tooth R_2 and R_1 respectively, until a new rotor tooth R_3 approaches this particular group of stator teeth. Then the flux *A* moves across to R_3 and flux *B* to R_2. On

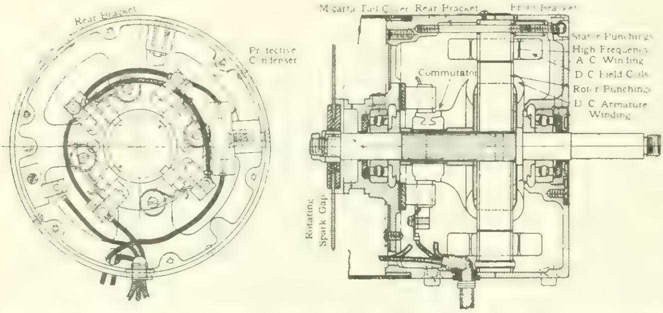


FIG. 6—SECTIONAL VIEWS THROUGH 900 CYCLE, 120 VOLT, 4500 R.P.M. INDUCTOR TYPE ALTERNATING-CURRENT GENERATOR

the stator the flux *A* has meanwhile traveled from T_1 to T_2 and back again, and flux B has traveled from T_3 to T_4 and back again, each accomplishing a complete cycle. The windings surrounding an individual tooth will be subject to variations in the magnitude of flux which it encircles. While the flux in T_1 and T_3 is decreasing the flux in T_2 and T_4 will be increasing. It will be seen, therefore, that the coils on consecutive teeth must be wound in opposite directions, as shown in Fig. 7. Since a decrease in the flux in one direction (say north flux) is equivalent to an increase in the flux in the opposite direction (south flux) the voltages induced in the coils of one group are in opposite direction to the voltages induced in the next group. Thus the whole winding on consecutive groups must be reversed.

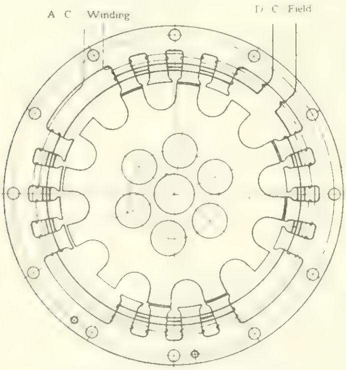


FIG. 7—PUNCHING DIAGRAMS

Showing the relation of the rotor teeth and slots to the stator teeth. The four groups of stator teeth form the four stationary magnetic poles with a direct current field winding around each. The high-frequency winding surrounds the individual teeth, consecutive coils being wound in opposite directions.

The fact that the flux follows the rotor teeth until the next rotor tooth approaches the particular pole (Fig. 8), will affect the voltage that may be excited in the rotor winding. It will be noticed that the flux in all rotor teeth shifts at the same time and follows along at the same time. The direct-current voltage generated in the rotor varies from zero to double the average, during each cycle of the alternating-current. The

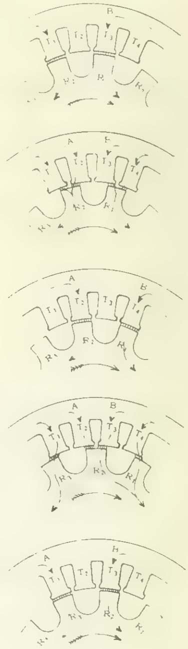


FIG. 8—DIAGRAM SHOWING THE MOTION OF THE MAGNETIC FLUX DURING ONE CYCLE OF THE ALTERNATING CURRENT

The flux follows the rotor teeth from T_1 to T_2 and then crosses the rotor slot from R_2 to R_3 while returning from T_2 to T_1. Thus the stator slots pass through alternating pulses while the rotor slots are subject to unidirectional pulses.

oscillogram in Fig. 10 illustrates the direct-current and alternating-current voltages. The field current has only a slight ripple, as the high inductance dampens out the pulsations.

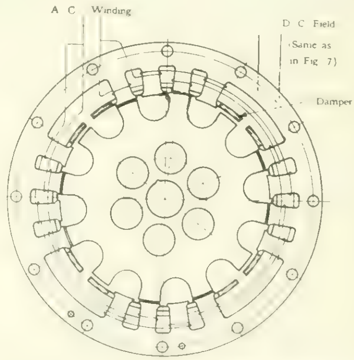


FIG. 9—PUNCHING DIAGRAM WITH MODIFIED WINDING TO PREVENT DEMAGNETIZING OF FIELD

The heavy copper dampers surrounding each pole minimize sudden changes of flux. The two high frequency alternating current windings surrounding alternate teeth and connected in parallel, greatly reduce the armature reactance.

In order to obtain a definite voltage on a self-excited machine, magnetic saturation must be introduced in some part of the magnetic circuit. The usual saturation of rotor or stator teeth must be avoided, as it

would cut down the alternating voltage more than it would the direct-current voltage. Variations of flux at great density would increase the iron losses considerably. The magnetic path between the poles is, therefore, restricted in two places by rivet or stud holes, as shown in Fig. 7, copper rivets or brass studs being used. The

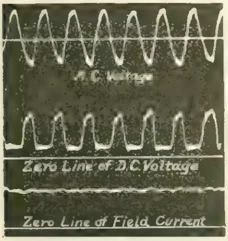


FIG. 10—OSCILLOGRAM OF NO-LOAD CONDITIONS

Although the direct-current voltage pulsates the inductance of the field keeps the field current nearly constant.

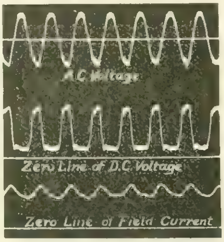


FIG. 11—OSCILLOGRAM OF NO-LOAD CONDITION WITH DAMPER WINDINGS AND DAMPER

The increased pulsations of the field current are caused by the fact that the damper carries the difference in magnetizing current.

resulting high flux density in the restricted path, even though it be very short, gives the necessary saturation characteristics. The total flux passing through this part of the circuit is constant, except due to the small pulsations in the magnitude of the field current. The iron losses due to high saturation are, therefore, minimized.

A definite picking up of voltage is a requirement stipulated for this generator. It was found that a residual magnetization of about 2.5 percent existed with the original type of construction. This gave a practically definite operation. The extremely few occasions of failure made it necessary, however, to introduce a flashing battery. In case the machine did not pick up current from the battery was passed for a short interval of time until the voltage built up.

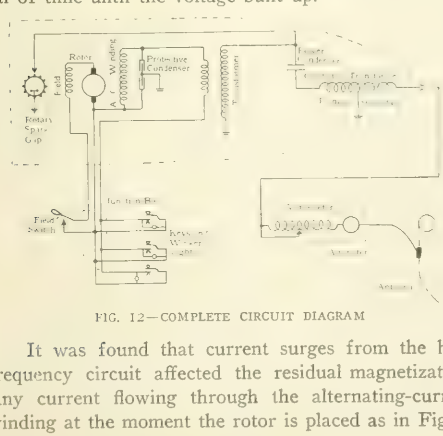


FIG. 12—COMPLETE CIRCUIT DIAGRAM

It was found that current surges from the high frequency circuit affected the residual magnetization. Any current flowing through the alternating-current winding at the moment the rotor is placed as in Fig. 7, exercises an armature reaction which either weakens or strengthens the field. To ensure a large amount of residual magnetization and a definite picking up the following changes were introduced; first, a copper damper was placed around each complete group; second, the winding was split into two independent circuits as in Fig. 9, each circuit containing coils on alternate teeth, and the two circuits being placed in parallel. For the position of the rotor shown in Fig. 9, one circuit will include coils opposing the rotor teeth, the other circuit, the coils opposing the rotor slots. The coils opposing the rotor teeth are those which will exercise large armature reaction. They will also have a higher reactance than the coils in the other circuit. A smaller proportion of current will go into the former coils and the armature reaction will be reduced. The improvement due to each of these changes was about equal. With both changes the residual magnetization under the worst surge conditions could not be reduced below one percent. Doubling the direct-current voltage further ensured the picking up, so that with this latter type of construction the flashing battery was omitted. The oscillogram shown in Fig. 11 was taken with the new winding. The field current can be seen to have larger

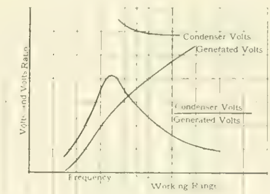


FIG. 13—VOLTAGE REGULATION IN THE POWER CIRCUIT

The resonance point of the circuit is below the operating frequency. A decrease in speed gives a smaller generator voltage but increased resonance; hence the condenser voltage is nearly constant.

pulsations than in Fig. 10. The copper damper carries the difference in the magnetizing current.

OPERATION OF SET

The full connections of the set are shown in Fig. 12. There are essentially five circuits as follows:—

1—The direct-current exciting circuit consisting of the rotating armature through the brushes, and field switch to the field windings on the stator, as shown in Fig. 3.

2—The alternating-current low-tension 900 cycle circuit consisting of the high-frequency winding on the stator with a protective condenser shunted across it, through a lead common to the direct-current armature to a junction box and from there to a number of keys, each shunted by winker lights. The keys may be located in the various parts of an airplane. The winker lights indicate whether the set is in operating condition, and whether anyone in the plane is using the set at the same time. The other side of the keys is connected to the low-tension side of the transformer, and from there back to the stator winding.

3—The high-tension 900 cycle charging circuit. One side of this circuit is grounded to the transformer core and from there to the framework of the airplane. The other side is connected to a power condenser. The power condenser is connected through the primary of an oscillation transformer to ground. Thus the high-tension winding is charging the condenser through the ground connection.

4—The condenser discharge circuit. On one side the condenser is connected through the primary of the oscilla-

tion transformer to ground; on the other side to the stationary spark point. The stationary spark point is mounted on an insulated support above the rotary spark disc, which is grounded through a pair of brushes. The spark disc is insulated from the shaft so that no discharge current is allowed to pass to the rotor and through the ball bearings to ground.

5—The secondary oscillation circuit or antenna circuit. The secondary of the oscillation transformer is grounded on one side. On the other side it is connected through the variable inductance or variometer and an ammeter to the antenna. The ground in each case is formed by the metal parts of the airplane.

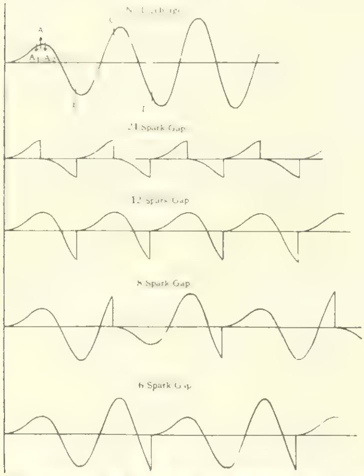


FIG. 14—VARIATION OF CONDENSER VOLTAGE WITH DIFFERENT SPARK GAP DISCS

With no discharge the voltage rises from the first to the fourth half cycle. Discharges occur every half cycle with the 24 spark disc; and every second, third and fourth half cycle with the 12, 8 and 6 spark gap disc respectively.

Certain features of the design of the transformer and the setting of the gap affect the operation of the set and the capacity of the generator. Three conditions must be met in operating the set, as follows:—

1—With varying speed the output should be approximately constant.
2—With different spark discs the output should be approximately the same in each case.
3—The note must be good in all cases.

The charging circuit is operated near the resonance point. The transformer and generator reactance are arranged to give resonance with the power condenser at a frequency a little below 900 cycles. As the speed

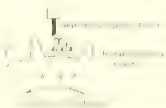


FIG. 15—[illegible] OF STATIONARY SPARK POINT FOR BEST OPERATION

A rising voltage as indicated by the points A_1, A and A_2 in Fig. 14 corresponds to a decreasing distance; hence a definite time of sparking results.

falls the generator voltage decreases. At the same time the circuit approaches the resonance condition. The ratio of voltage on the condenser to the generated volts is, therefore, greater, while the actual value of condenser voltage is practically constant. This is illustrated in Fig. 13, and fulfills the first condition.

There are five different interchangeable spark gap discs which serve to produce five different wave train frequencies. Each frequency results in a distinctive note in the receivers. A 24 spark disc will give a discharge of the condenser every half cycle, a 12 spark disc every other half cycle, etc. The following discs are used:

Number of points — 24	Frequency of note obtained 1800.
Number of points — 12	Frequency of note obtained 900.
Number of points — 8	Frequency of note obtained 600.
Number of points — 6	Frequency of note obtained 450.
Number of points — 17	No definite frequency.

Since the charging circuit is operated near resonance, the condenser voltage does not reach its maximum in one-half cycle, but rises gradually, as shown in Fig.

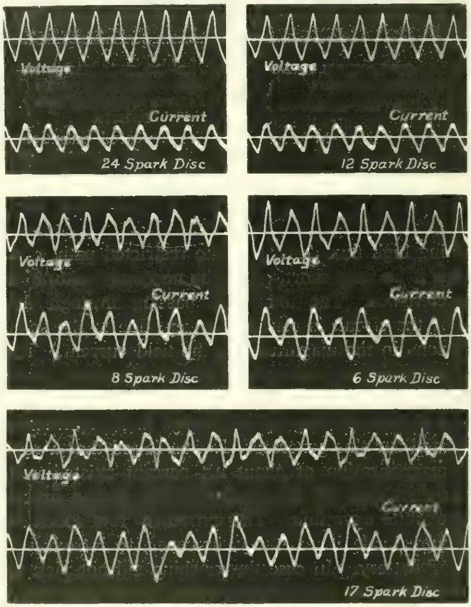


FIG. 16—OSCILLOGRAM OF CHARGING CURRENT AND GENERATOR VOLTAGE ON LOAD

Note the relation between the curves for the charging current and those drawn for the condenser voltage in Fig. 14. The voltage in the generator is nearly in phase with the current; this good power-factor being the result of the proper choice of transformer reactance and the proper setting of the spark point. The 17 spark nonsynchronous disc gives an irregular discharge, producing a grinding sound of no particular frequency or tone.

14. Thus a discharge occuring during the fourth half cycle will be with a condenser voltage higher than a discharge during the first half cycle. The power output is proportional to the charge on the condenser (that is to the square of the voltage) and to the number of discharges. With the discharges every fourth half cycle, the voltage must be double that with the discharge every half cycle. By correct choice of the resonance point, that is design of transformer and generator reactance, this can be accomplished and the second condition fulfilled.

In order to get a clear note the time be-

tween discharges must be very definite. In other words, the discharge must occur at exactly the same part of the charging wave during every half cycle. Fig. 14 shows the points *A, B, C,* and *D* as respective points of discharge of condenser with 24, 12, 8 and 6 spark gaps. It will be seen that the discharge takes place while the voltage is still rising. Fig. 15 shows the position of the rotating and stationary spark points for discharge occurring at point *A* on Fig. 14. The discharge occurs while the rotating point is approaching the stationary point. A rising voltage and a decreasing distance between spark points combine to make the time of discharge definite. Thus the setting of the spark point will determine the clearness of the note and accomplish the third condition. The radial length of gap has little influence except that the minimum distance will secure operation even if the voltage falls below the working range. The stationary spark point can be set radially and also circumferentially. It is this latter setting that secures the right note. Power output can be varied within certain limits by the same setting. Advancing the spark point along the direction of rotation will delay the discharge and allow the condenser voltage to build up to a higher value, resulting in a larger power output.

The oscillograms in Fig. 16 show the charging current and the voltage across the transformer for various spark discs. The curves with the eight and six spark discs show the rising values from first to fourth half cycle. The voltage curves show the discharge taking place early in the last half cycle of each charging period. The curve with the 17 spark disc shows the discharge taking place at indefinite intervals; the result is a harsh sound without definite tone.

The oscillation transformer carries taps both on the primary and secondary windings. Nine primary taps give as many different wave lengths. The five spark discs give five possible wave train frequencies, separable by the resulting sound in the receiver. The nine oscillation transformer taps give nine different oscillation frequencies separable by tuning the receiver circuit. Thus 45 separable combinations are possible. The signal from each airplane on each group of airplanes can thus be separated, as each plane or each group of planes will have a distinctive combination.

FUTURE DEVELOPMENTS

The use of a set of similar nature by amateurs is anticipated. Simplicity in design and operation are its chief advantages. It offers a compact and inexpensive instrument with quite a considerable range. The generator has been adapted to be driven by an induction motor from a 60 cycle supply circuit. Vacuum tube wireless telegraph transmitting sets are also receiving much attention. It must be remembered however, that the cost of either is still very high, while a satisfactory operation often requires careful and complicated adjustment. The range of a tube set is, of course, rather small. The spark set does not have these disadvantages and it is still the standard means of transmission on small and medium sized stations. This spark set is just another case where war time developments may find a practical application during peace times.

Essentials of Transformer Practice-XXI

Voltage Transformations with Autotransformers

E. G. Reed

An AUTO-TRANSFORMER has a single winding which must perform the functions of both the primary and secondary elements of a two-winding transformer. For this reason it is to be expected that an autotransformer may be built with less material, and that its efficiency and regulation will be superior to a two-winding transformer of the same rating. The main objection to the use of the autotransformer in a large number of cases, where it might otherwise be used to advantage, is the fact that the primary and secondary circuits are not electrically separated.

RELATION BETWEEN VOLTAGE RATIO AND OUTPUT RATING

Fig. 1 shows an autotransformer whose high-voltage is E_1 and whose low-voltage is E_2. The current in the high-voltage lines is I_1 and the current in the low-voltage lines is I_2. Since the current I_2, as it enters the winding at *A*, divides in such a ratio that the ampere-turns on each side of the tap are equal, it follows that the products of the current and voltage on each side of the tap are equal. The product of the voltage and current expressed in k.v.a. on the right of the tap in Fig. 1 is $(E_1 - E_2)\ I_1$. The output of the autotransformer is $E_1\ I_1$, therefore,—

$$\frac{\text{K.v.a. of transformer parts}}{\text{K.v.a. transformed}} = \frac{E_1 - E_2}{E_1} = 1 - \frac{E_2}{E_1} \quad \ldots\ldots (1)$$

Since the ratio of voltage transformation R of the autotransformer is $\frac{E_1}{E_2}$ equation (1) may be put into the form,—

$$\frac{\text{K. v. a. of transformer parts}}{\text{K. v. a. transformed}} = 1 - \frac{1}{R} \quad \ldots\ldots\ldots (2)$$

Example—If a transformer which has a voltage ratio of 2300 to 460 be connected as an autotransformer, what should the normal rating of the transformer be so as to give a 12 k. v. a. output as an autotransformer?

From equation (2),—

$$\text{K.v.a.} = 12\left(1 - \frac{1}{\frac{2760}{460}}\right) = 10.$$

Fig. 2 shows the rating of the transformer parts which are required for a given transformation, as a percentage of the k.v.a. transformed, for various voltage ratios of transformation. It is apparent that the rating of the transformer parts increases rapidly with

increasing ratios of transformation up to 5, and, for ratios greater than 10, is practically constant.

Since a two-winding transformer can be reconnected as an autotransformer and give an increased rating, it is evident that, with the same rating, the autotransformer could be built with less material. When the transformer windings are reconnected to form an autotransformer with a greater output rating, the current densities and consequently the losses remain the same and, since the output has increased, the efficiency is increased. Since the percentage copper loss is less, the regulation at high power-factors is evidently improved. It now remains to show the effect on the percentage impedance of the transformer when it is reconnected to form an autotransformer.

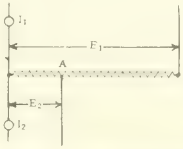


FIG. 1—WINDINGS OF AN AUTOTRANSFORMER

RELATION OF TRANSFORMER TO AUTOTRANSFORMER IMPEDANCE

The impedance of a two-winding transformer may be determined by short-circuiting the high-tension winding and impressing voltage on the low-tension winding; or by short-circuiting the low-tension winding and impressing voltage on the high-tension winding. If E be the voltage required to circulate full-load currents in the windings in either case, and E_n be the normal voltage of the winding upon which the voltage E is impressed, by definition,—

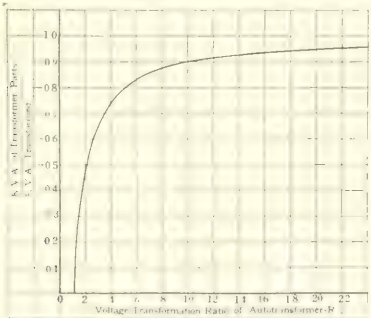


FIG. 2—EFFECT OF VOLTAGE TRANSFORMATION RATIO OF AN AUTOTRANSFORMER

On the ratio of the k.v.a. of transformer parts to the k.v.a. transformed.

$$Z_T = \frac{E}{E_n}$$

If I_n be the normal current in the circuit upon which voltage is impressed, this equation may be written,—

$$Z_T = \frac{E\,I_n}{E_n\,I_n}$$

In other words,—

$$Z_T = \frac{\textit{Volt-amperes taken on short-circuit}}{\textit{Rated volt-amperes of transformer}}$$

Similarly, the impedance of an autotransformer is,—

$$Z_A = \frac{\textit{Volt-amperes taken on short-circuit}}{\textit{Rated volt-amperes of autotransformer}} \cdots\cdots (3)$$

If $E\ I_n$ be the volt-amperes taken on short-circuit by a two-winding transformer connected by either of the methods shown in Fig. 3, and $E_n\ I_n$ is the normal output rating of the transformer, the impedance as shown by equation (3) is,—

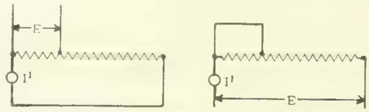


FIG. 3—CONNECTIONS FOR MEASURING THE IMPEDANCE VOLTS OF AN AUTOTRANSFORMER

$$Z_A = \frac{E \quad I_n}{(E_n\ I_n)\ \frac{R}{R-1}} \cdots\cdots\cdots\cdots\cdots\cdots (4)$$

The output rating of the autotransformer being taken from equation (2) as being $\left(\frac{R}{R-1}\right)$ times the rating of the windings connected as a transformer,

$$\text{Or } Z_A = \frac{E}{E_n}\left(\frac{R-1}{R}\right)$$

Now $\frac{E}{E_n}$ is the impedance of the windings connected as a transformer, therefore,—

$$Z_A = Z_T\left(1 - \frac{1}{R}\right) \cdots\cdots\cdots\cdots\cdots\cdots (5)$$

It is evident from the preceding that the lower impedance of the windings connected as an autotransformer is due to the greater output rating of the autotransformer as compared to the output rating of the windings connected as a transformer. The impedance of an autotransformer may be measured directly by either of the connections shown in Fig. 3, and the above

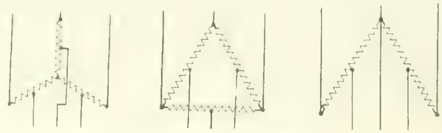


FIG. 4—STAR CONNECTION
FIG. 5—DELTA CONNECTION
FIG. 6—OPEN DELTA CONNECTION

demonstration is given only to show the relation between the impedance of the two windings connected as a transformer and as an autotransformer.

Example—If a 10 k. v. a. transformer having voltages of 2300 to 460 volts, has an impedance of three percent, its percent impedance connected as a 12 k. v. a. autotransformer will be,—

$$Z_A = 3\left(1 - \frac{1}{\frac{2300}{460}}\right) = 3 \times [illegible] = [illegible] \text{ percent.}$$

Since both the percentage copper loss and reactance is less for the windings connected as an autotransformer, the regulation will be better at all power-factors.

THREE SINGLE-PHASE AUTOTRANSFORMERS

Three single-phase autotransformers may be connected in star as shown in Fig. 4 to secure a three-phase

transformation. The k.v.a. of transformer capacity required depends on the ratio of voltage transformation, and bears the same ratio to the k.v.a. transformed as do the same quantities for a single autotransformer performing a single-phase transformation. While a three-phase voltage transformation may be secured by the connections shown in Fig. 5, this arrangement is not practicable except for special cases, and for small ratios of voltage transformation, because of its inefficiency. For example, with a voltage ratio of 2 to 1 as shown in Fig. 5, the output would only be one-half of that for the star connection shown in Fig. 4 with the same k.v.a. of transformer capacity. The low voltage of a single-phase auto-transformer, or of the star-connected group shown in Fig. 4, is in phase with the high voltage. But with the connection shown in Fig. 5 there is a phase rotation of the delivered voltage as compared to that impressed. This is a further objection to this

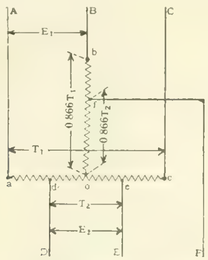


FIG. 7—T CONNECTION

connection, as parallel operation would not be possible with the star connection shown in Fig. 3.

TWO SINGLE-PHASE AUTOTRANSFORMERS CONNECTED IN OPEN DELTA

Two single-phase autotransformers may be connected in open delta as shown in Fig. 6, to secure a three-phase transformation. The k.v.a. of transformer capacity required for the transformation depends on the ratio of voltage transformation, and requires approximately 15 percent more capacity than a single-phase autotransformer, making the same voltage transformation single-phase. The additional capacity required is the same as that required by two single-phase transformers operating open delta. Aside from the question of capacity the open delta connection has an advantage as compared to two T-connected antotransformers in that the units are duplicates of each other, and there is no possibility of bad regulation as with the T connection if the two halves of the main autotransformers are not properly interconnected.

T-CONNECTED AUTOTRANSFORMERS

Two transformers are shown in Fig. 7 T-connected for a three-phase to three-phase transformation. The k.v.a. of the teaser is the sum of the products of the voltage and currents in the two parts or,—

$$K.v.a. = 0.866\, E_2 I_{fo} + (0.866\, E_1 - 0.866\, E_2)\, I_{bB} \quad \text{(6)}$$

But,—

$$I_{fo} = I_{Ff} + I_{Bb} \quad \text{(7)}$$

Also, since the currents on the high and low voltage sides of the group are inversely as the voltages,—

$$I_{Ff} = \frac{E_1}{E_2} I_{bB} \quad \text{(8)}$$

Substituting this value of I_{Ff} in equation (7) gives,—

$$I_{fo} = \left(\frac{E_1}{E_2} - 1\right) I_{bB}$$

Substituting this value of I_{fo} in turn in equation (6) gives,—

$$K.v.a. = 1.73\, I_{bB}\, (E_1 - E_2) \quad \text{(9)}$$

Similarly the k.v.a. of the main autotransformer is,—

$$K.v.a. = E_2 I_{do} + (E_1 - E_2)\, I_{bB} \quad \text{(10)}$$

Substituting the value of I_{do} in terms of I_{bB}, which is a similar relation to that expressed in equation (8) gives,—

$$K.v.a. = 2\, (E_1 - E_2)\, I_{bB} \quad \text{(11)}$$

The k.v.a. transformed is,—

$$K.v.a. = 1.73\, I_{bB}\, E_1 \quad \text{(12)}$$

Now from equations (9) and (12),—

$$\frac{K.v.a.\ of\ teaser}{K.v.a.\ transformed} = \frac{1.73\, I_{bB}\, (E_1 - E_2)}{1.73\, I_{bB}\, E_1} = 1 - \frac{E_2}{E_1} \quad \text{(13)}$$

Also from equations (10) and (12),—

$$\frac{K.v.a.\ of\ main\ unit}{K.v.a.\ transformed} = \frac{2\,(E_1 - E_2)\, I_{bB}}{1.73\, I_{bB}\, E_1} = 1.15\left(1 - \frac{E_2}{E_1}\right) \quad \text{(14)}$$

and,—

$$\frac{K.v.a.\ of\ both\ units}{K.v.a.\ transformed} = 1 - \frac{E_2}{E_1} + 1.15\left(1 - \frac{E_2}{E_1}\right) = 2.15\left(1 - \frac{E_2}{E_1}\right) \quad \text{(15)}$$

If the ratio of transformation is,— $R = \frac{E_1}{E_2}$, equation (15) may be written,—

$$\frac{K.v.a.\ of\ both\ units}{K.v.a.\ transformed} = 2.15\left(1 - \frac{1}{R}\right) \quad \text{(16)}$$

This expression gives the total k.v.a. of the autotransformers, and to put it on the same basis as for a two-winding transformer, the expression must be divided by two. The k.v.a. of a two-winding transformer is not the product of the current and voltages for both primary and secondary windings, but the product for one winding only.

Therefore, equation (16) becomes,—

$$\frac{K.v.a.\ of\ both\ units}{K.v.a.\ transformed} = 1.075\left(1 - \frac{1}{R}\right) \quad \text{(17)}$$

As is to be expected this expression is the same as for two T-connected transformers except for the addition of the term $\left(1 - \frac{1}{R}\right)$, which takes care of the autotransformer feature.

TABLE I—RATIO OF THE K.V.A. OF TRANSFORMER CAPACITY TO THE K.V.A. TRANSFORMED FOR THE VARIOUS THREE-PHASE CONNECTIONS

Connection	Ratio
Three autotransformers star connected.....	$1.0\left(1 - \frac{1}{R}\right)$
Three autotransformers delta connected....	greater than $\left(1 - \frac{1}{R}\right)$
Two autotransformers, open-delta connected	$1.15\left(1 - \frac{1}{R}\right)$
Two autotransformers, T connected.......	$1.075\left(1 - \frac{1}{R}\right)$

Regulation of Automotive Generators

W. A. Dick

THIS PAPER deals with the regulation characteristics of generators used for lighting and other purposes on automobiles and kindred machines. It describes only those types that have been developed and put into commercial use.

ELECTRIC lighting has come into universal use on all types of automotive apparatus and for the same reasons that have led to its use so generally elsewhere. As now employed it involves the installation of a small power plant on the vehicle, with the necessary control apparatus and a storage reservoir to furnish power when the engine is idle. The essential features of this power plant are the generator driven from the engine, a storage battery, usually of the lead plate type, a switch for connecting the generator automatically to the battery at the proper time and disconnecting it when the engine stops, circuits to the lights and manually-operated switches to control them.

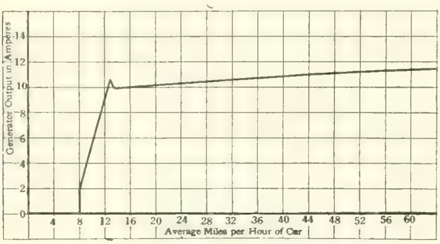


FIG. 1—OUTPUT OF A CONSTANT CURRENT GENERATOR WITH VARYING SPEED

One of the most important elements in this power plant is the generator, for the success of the equipment depends on its proper operation. To meet the requirements it must maintain a suitable output:—

1—Over a wide speed range of at least five or six to one. This would correspond to a car speed from ten to fifty or sixty miles.

2—Preferably it should give a greater output in winter than in summer, because the longer nights of winter require a greater use of the lights and the engine requires longer cranking by the starting motor.

3—It must not overcharge the battery injuriously and yet it should give sufficient output to keep it charged.

4—It must require little attention and be unaffected by the heat of the engine, or by oil and water.

The single wire system is now in almost universal use, the metal frame of the car being used for the return circuit; hence one side of the generator, battery, lamps, etc. is grounded to the frame.

Probably the most difficult condition to meet in the generator is that of securing sufficient uniformity in output over the wide range of speed. The storage battery is of itself a good regulator and, in nearly all systems of generator regulation, it is an integral part of the system and the generators cannot be operated without it. An exception to this is the voltage regulator system (to be described later) which is capable of operating without a battery.

In general, regulation is secured by controlling the voltage developed by the armature. This is usually accomplished by varying the magnetic flux from the field poles, the flux required varying approximately inversely with the speed. There are several ways in which this has been accomplished. Two types of regulation have been developed and produced in commercial quantities. In one the current output of the generator is maintained at an approximately constant value; in the other the voltage is held constant. The output of the first will be practically the same whatever the condition of the battery; that of the second will vary with the condition of charge in the battery. When the battery is discharged the output will be relatively high and when full correspondingly low.

CONSTANT CURRENT TYPES

The current is held practically constant and the voltage varies to produce this result. A single exception to the flux control may be mentioned here. In an early type of generator, a constant current output was obtained through securing a constant speed of the armature by the use of a slip clutch—a purely mechanical scheme. The clutch, through which the armature was driven, was so adjusted that slippage occurred at all speeds above that required to give the torque corresponding to the current desired. Provision had to be made for dissipating the extra heat produced by the friction of the clutch on the stationary part. A fairly successful machine was produced, but inefficient, as the energy consumed in the clutch by the friction was proportional to the slippage. For instance, if the clutch was set to slip at 1000 r.p.m. of the armature, and the speed of the drive shaft increased to 3000 r.p.m., two-thirds of the energy put into the generator would be wasted in friction alone. Fig. 1 gives a characteristic curve of this type of machine. Adjustment of output after installation could be made by varying the slippage point of the clutch.

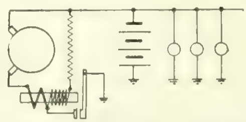


FIG. 2 SHUNT WOUND GENERATOR

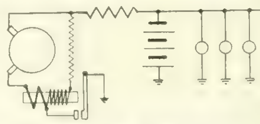


FIG. 3 STRAIGHT BUCKING SERIES GENERATOR

In Fig. 1, as well as in the other diagrams shown, the point at which the curve cuts the base line represents the speed at which the magnetic clutch closes and connects the generator to the battery. The current output increases very rapidly with the increase in speed, in all systems, to the point where the curve bends. In the slipping clutch arrangement, the armature speed and consequently the current remains practically constant beyond the bend. A shunt winding is used to excite the field of the generator and produce the flux through the armature which remains constant over the range of operating speeds, Fig. 2.

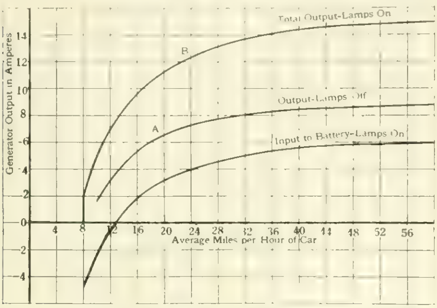


FIG. 4—OUTPUT CHARACTERISTICS OF A BUCKING SERIES GENERATOR
Of the types shown in Figs. 3 and 5.

If to a shunt wound generator another winding be added to the field poles through which the current to the battery is passed and which is so connected that the flux set up by it opposes the main flux set up by the shunt field winding, a "bucking series" type of regulation is secured. The flux passing through the armature is so reduced, as the speed increases, that a satisfactory regulation characteristic is obtained when connected to a storage battery. In fact the battery limits the voltage and the current output is determined almost entirely by the series winding and the speed. Armature reaction at the higher speeds, as the field flux becomes greatly reduced, also assists in holding down the current output.

Bucking series regulation is a reliable type which undergoes no adjustment change due to service conditions. The only adjustment that can be made after installation is to increase the output by placing a resistance in shunt connection with the series coil to reduce the "bucking" effect of the battery current. In this type the current is not strictly constant but increases somewhat with the speed. There is also some reduction in output with increase in temperature, thus affording an inherent temperature control within rather narrow limits.

There are a number of different modifications of the bucking series machine. The simplest form, which may be called a straight bucking series, is one in which all the external current passes though the series winding. The arrangement of windings and connections to the battery and lamps is shown in Fig. 3. A typical output curve of such a machine is shown in Fig. 4 curve *A*. It is not materially changed by switching on the lighting load. A very desirable characteristic, in which the output is automatically increased when the lamps are burning, is secured by connecting the lamp circuit inside the series winding, as shown in Fig. 5. Curve *B*, Fig. 4, represents the output under this arrangement with lights on, while with lights off the output drops to that of curve *A*. This refinement adds much to the success of an installation, and is in wide use.

Where it is considered desirable to obtain an adjustment of output over a greater range than will be given inherently by the windings themselves with change in temperature, two connections are sometimes brought out from the series winding as shown in Fig. 6. By connecting the lamp circuit to one or the other of the two terminals, two different outputs can be obtained corresponding in general to curves *A* and *B*, Fig. 4. There appears to be very few applications where the inherent temperature control will not satisfactorily meet the requirements.

Advantage is taken in still a different system, using the bucking series control, of the characteristic of an iron wire ballast coil of greatly increasing its resistance at a certain critical temperature just below the red heat. Such a ballast coil enclosed in a glass tube, from which the air is exhausted, is connected across the series windings, Fig. 7. The resistance of this winding to the flow of the current is considerably greater than that of the ballast coil when the latter is at a low or moderate temperature. At low engine speeds practically all the current is shunted through the ballast coil. As the speed increases the output of the generator also increases, until at a certain value the critical point of the ballast coil is reached, after which no more current will pass, but the excess is shunted through the series coil and a bucking action takes place, the same as with a straight bucking series machine. The output can be increased only as with the straight bucking series, i. e., by shunting the series winding.

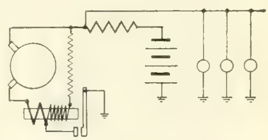


FIG. 5—BUCKING SERIES GENERATOR
With increased output when lamps are burning.

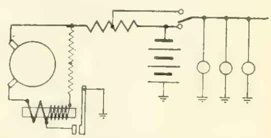


FIG. 6—BUCKING SERIES GENERATOR WITH ADJUSTABLE OUTPUT

Another type of current control generator is one where the output is controlled by a separate regulator. In an early arrangement, the resistance of a field rheostat, with a large number of connections brought out to a face plate and connected in series with the shunt field, was varied by a contact arm operated by a magnet, energized by a shunt and series winding, the shunt winding being connected across the terminals of the generator and the series winding between the generator

and the battery, so that the battery charge passed through it. As the speed of the engine increased the generator would begin to develop a higher voltage which would tend to send more current to the battery. As soon as the current started to increase, the magnet through the influence of its windings, would move the contact arm and cut more of the rheostat into the field circuit and a balance would be reached, the current being held at the predetermined value.

To overcome the friction elements in such a regulator, and to secure positive action, the parts must be relatively large, and consequently this equipment is not so economical of material as others; as a result it has largely been replaced by a form of vibrating regulator in which a permanent resistance in the shunt field is bridged by a pair of vibrating contacts. The proper amount of resistance in the field circuit, to give the desired output at any point, is secured by varying the amount of time the contacts are closed, short-circuiting the resistance, instead of varying the amount of resistance as in the previous case. As the action is the same as in the constant voltage type of regulator, which will be described later, the reader is referred to that part of this article for a more complete description. The only essential difference is that the contact coil is wound

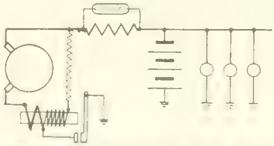


FIG. 7—BUCKING SERIES GENERATOR WITH BALLAST CONTROL

for current instead of voltage. Constant current thus obtained does not seem to have any particular advantage over the other arrangements previously described. The output can be varied by changing certain adjustments provided for the purpose.

Third Brush Regulation—Generators with this type of regulation have come into very general use and have a number of attractive features. The regulation is inherent, as in the bucking series type, but less material is required for a given output. Third brush machines have a shunt field winding only. Instead of being connected between the two main brushes, one terminal of the winding is connected to a main brush and the other to a separate, or third brush, as it is called. This brush is placed on the commutator between the two main brushes. Regulation is due to the field distortion caused by the reaction of the magnetic flux set up by the armature, resulting in a variation in density of the magnetic flux from the field poles. The density of the flux on one side of the pole is reduced while it is increased on the other side. This shifting of the field flux varies the voltage across the shunt field and hence the exciting current decreases as the armature current increases. But part of the armature current goes to the battery as shown in Fig. 8; the rest of it circulates in the armature itself.

Third brush type of regulation produces a comparatively large output over the lower range of speeds, and a reduced output over the higher range. A proper application of this type is one that gets the large output at town speeds, and the lower output at touring speeds. Fig. 9 shows the arrangement of circuits.

Besides the inherent regulation of current output, there is also an inherent variation of output with temperature. Fig. 8 shows the output of a typical machine at normal temperature—about 70 degrees F—cold and hot. A considerable increase in output above the cold curve is shown when the temperature is below 70 degrees F. In this way the difference in output requirements due to summer and winter running requirements are adequately taken care of. It is possible to increase the range between hot and cold output by the use of a thermostatic switch and a resistor unit which is applied to the field winding, Fig. 10. This arrangement has been used to a certain extent. The generator is set for a higher output when cold than would be safe for continuous operation, dependence being placed on the thermostatic switch for cutting down the output at

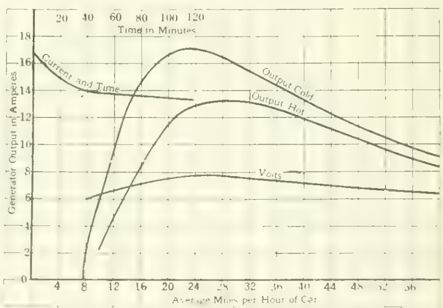


FIG. 8—OUTPUT CHARACTERISTICS OF THIRD BRUSH GENERATOR

a certain predetermined temperature. This switch opens and cuts a resistance into the shunt field circuit which immediately reduces the output. As the resistance is either all in or all out, there are two output curves with no output between. This arrangement appears to have no material advantage over the inherent regulation for temperature and adds complication.

CONSTANT VOLTAGE TYPES

In these types the voltage is held constant and the output varies with the external load conditions. All systems are controlled by a regulator which is either placed inside the frames of the machines or mounted separate from them. They all control the current in the field winding. A constant voltage offers a number of advantages for supplying power to meet widely varying conditions of automotive service. It returns a battery to a fully charged condition more quickly than any other, The output increases when the lights are switched on. When the battery is fully charged the output of the generator is reduced to a small amount, thus preventing over-heating and injury to the battery

and there is consequently less occasion for supplying water; all of which tend to prolong the life of the battery. The demand for power from the engine is reduced and the equipment is, therefore, more economical.

An earlier type was somewhat similar to the field rheostat arrangement, described under "Current Regulation Types". It was similar but the contact arm and face plate have been eliminated and the resistance is wound on the end of the magnet. The lower end of the resistance floats on a mercury bath, which completes the circuit. It is evident that by increasing the immersion of the resistance in the mercury a variation in the amount of the resistance in the field circuit can be secured. This variation is secured through a magnet coil excited from the terminals of the machine. If there were no other forces acting on it than the buoyancy of the mercury and gravity, the magnet would always remain in a certain position. However, the magnet is acted upon by the coil, the effect being to withdraw it from the mercury bath as the current in the coil increases; the more the magnet is withdrawn, the greater the amount of resistance cut into the field circuit, and in this way regulation is secured.

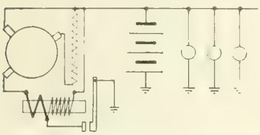


FIG. 9—THIRD BRUSH GENERATOR

The essential parts of voltage regulating devices are a resistance connected in series with the field winding of the generator, two contact points—each one of which is connected to a terminal of the resistance. A magnet is provided, excited by current from the generator, this magnet acting on a lever of magnetic material on which one of the contacts is mounted. A spring attached to the lever hold them in contact, and the pull of the magnet works against the spring by variation of which adjustment is secured. The contacts are in constant vibration, being opened and closed very rapidly. The regulation is secured by the variation in time in which the contacts are closed, which varies with the speed at which the generator is being driven, as follows:—

At all speeds below that at which the generator gives the desired voltage, the contacts remain closed. When this speed is exceeded the generator tends to increase its voltage. As soon as this point is reached the contacts are separated and the resistance is thereby cut into the field. This immediately lowers the voltage, but as soon as it starts to decrease the magnet releases its hold on the contact lever and the contacts close again. This action continues with extreme rapidity so as to be invisible to the eye, and without causing flicker in the lights. Very satisfactory regulation is obtained within the narrow limits required by a battery. Owing, however, to the narrow limits in range of voltage which must be secured, the active parts must be relatively light, so that this type is somewhat sensitive to the external conditions existing on an automobile. It is, however, in quite extensive use.

To retain all the advantages of the voltage control, and to secure a more substantial construction and an increase in the forces used, a modification of this type has been developed. In this the vibration is secured by a *cam,* mounted on the shaft of the armature, which is in contact with a pivoted lever that carries one of the contact points. A positive vibration is thus secured, and the action is undisturbed by car vibrations or other external conditions. The other contact is mounted on a magnetic lever whose position is controlled by a spring; the magnet acts on this lever and changes its position so that its contact point is either touching the other contact point or is drawn away out of contact with it. The resistance is thus alternately cut in and out, and regulation secured. Fig. 11 shows how the output of the generator varies with the battery conditions.

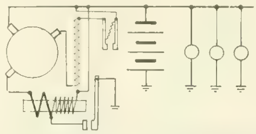


FIG. 10—THIRD BRUSH GENERATOR WITH THERMOSTATIC CONTROL

It would appear that the advantages of a voltage regulation type of machine are such as to result in its more general use as these advantages become known. At the present time it is the latest development in automobile generators, and is the only one which will operate without a battery.

A review of methods used to secure regulation of automobile generators, such as this, would not be complete without some mention of the important part that the storage battery plays in this. All of the devices described except the vibrating voltage regulator require the use of a battery; in fact, the battery is a good regulator in itself. It will stand charging and discharging at wide variations in current, and the difference between charge and discharge voltage is small. The tungsten lamp has also had an important bearing upon successful automobile lighting, both in its economy in the use of energy and allowable variation in voltage.

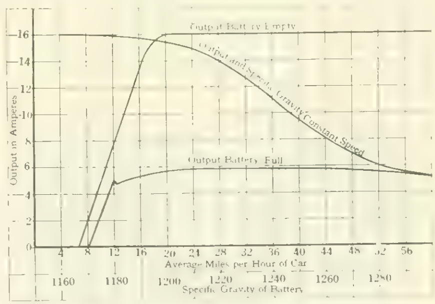


FIG. 11—BATTERY CHARGING CHARACTERISTICS OF A VOLTAGE REGULATOR GENERATOR
With varying conditions of battery and car speed.

Designing Moulded Insulation

W. H. Kempton

IN designing moulded insulation, two things should be always in mind. The block must be manufactured and it must perform its work without failure. There are many things to consider in designing a block that can be moulded readily and the mould for which will be sufficiently rugged to have long life and few trips to the tool room for repairs. If possible, one experienced in insulation moulding should be consulted.

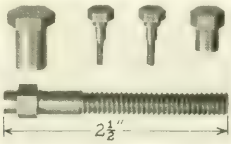


FIG. 1

If such a man is not available, the drawing should be submitted for criticism to one or more companies doing moulding work. Much trouble to both the designer and manufacturer has resulted from lack of this cooperation.

The following suggestions are offered as a help to the designer, in getting his design ready for criticism by the manufacturer.

1—The simpler the form of the moulded block, the cheaper will be the mould, the more perfect will be the piece, the more rapid will be the production and the cheaper will be the product. The ideal form to mould would be a circular block with flat top and bottom and tapered sides. The nearer the design conforms to this ideal, the more satisfactory will be the results.

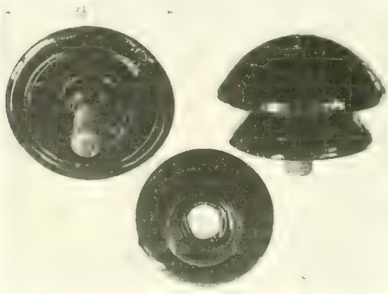


FIG. 2

2—All vertical sides should, if possible, be tapered in the same direction. If the block is pressed out of the mould, straight vertical faces are sure to score, thus causing sticking of the moulded block. If straight sides are necessary they can be formed by providing loose liners in the mould that are pushed out with the block and then removed. Such moulds are more expensive and more time is required to handle the additional loose parts.

3—Rounded corners on the outer edge of both top and bottom faces require liners in the mould. Otherwise, the pressing blocks will have sharp, thin edges that are soon damaged, resulting in ragged corners instead of rounded corners. A rounded edge may be placed on either the top or the bottom face without liners if the sides are tapered and the rounded corner placed at the small end of the taper.

4—Avoid so far as possible the moulding of holes in the sides of blocks. The thrust of the composition against the projecting part of the mould is very apt to distort this part. The pressure on the composition may be two or three tons per square inch, therefore, severe strains are imposed on all parts of the mould projecting from the sides.

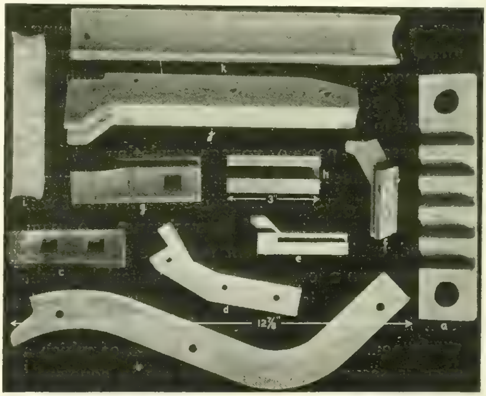


FIG. 3

5—Do not call for a moulded thread if it can be avoided. The composition hugs the threaded part of the mould very closely and the least damage to the thread on the mould tears the formed thread when the piece is removed. A threaded metal insert is much to be preferred. If a moulded thread must be used, make it as coarse as possible and as short as possible. The difference in contraction between the composition and metal will lock the thread if it is too long. A taper on the thread is highly desirable.

6—Threaded metal inserts may readily be moulded into the top and bottom faces of the block. In such cases keep the size of the insert as small as possible and provide a positive anchor. Hexagon stock with a shoulder is much better than a knurled insert. All the inserts shown in Fig. 1 are designed with a long shoulder and short head so that the strength of the supporting insulation will be as nearly as possible equivalent to the strength of the anchoring head.

7—Specify inserts moulded in the sides of a block only as a last resort. When used, make them as short as possible and provide for a heavy supporting pin to hold the insert to the mould during the moulding

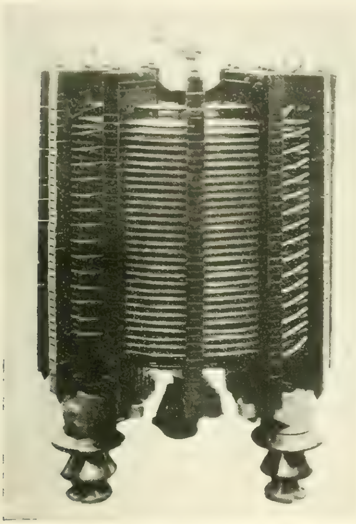


FIG. 4

process. In other words, use a large diameter threaded stud or screw with such inserts.

8—Avoid imbedding large pieces of metal in a moulded block. The difference in contraction when the piece cools from the moulding temperature to the air temperature may crack the insulation or set up strains that will result in cracking at a later period.

These directions are of a general nature and will apply to any variety of composition. Much additional information is necessary, bearing on each variety, to enable the designer to present the moulder with a satisfactory design. The following paragraphs deal with

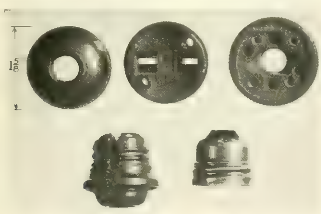


FIG. 5

the peculiarities of the different varieties as they affect the design.

DESIGNING OF COLD MOULDED PIECES

The cold moulded materials as a class flow with difficulty when being moulded. The binder is not so strong as that used for hot moulded materials so a long fibre filler is used to secure sufficient strength. Long fibre in a mixture retards the flow. Then the binder is not active when the block is removed from the mould so the product is weak and easily broken. The warning is—do not ask for high thin walls on a cold moulded block. Such walls either will not form or will break when removed from the mould. All corners around which the material must flow should be rounded to facilitate the flow.

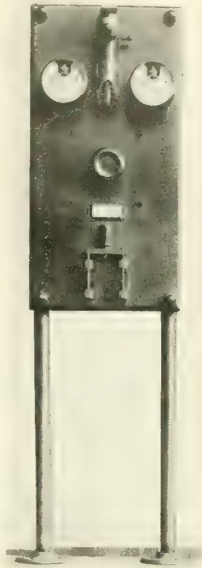


FIG. 6

Examples of Cold-Moulding—Cold moulded materials, especially those with a non-softening binder, can be made of considerable value. Fig. 2 represents a cap and cone trolley hanger made from a cold-moulded material of this class. This hanger can be heated to a red heat, quenched in a bucket of water, dried, painted and put back into service. The only damage resulting will be the burning away of some of the water-proofing ingredient and finish. Such a hanger is much better adapted for use in hot locations, such as around coke ovens and in the hot portions of the South, than hot moulded mixtures that soften when heated. As a matter of fact they will probably stand in any climate better than the hot moulded shellac mixture hangers owing to their better weathering qualities and rugged design.

Fig. 3*a* shows a "reactance cleat" used in building

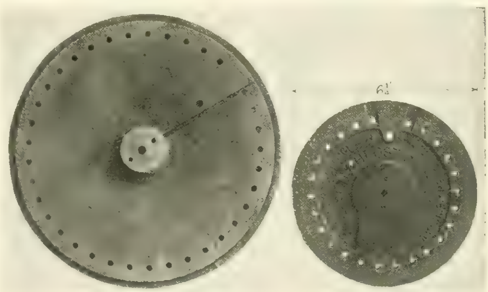


FIG. 7

up the reactance coil, Fig. 4. This service requires a material not subject to burning with leakage currents. Fig. 3*b* to *k* shows spacers for arc boxes for magnetic blow out unit switches. These pieces also have the holes moulded in. This material must be arc resisting.

Fig. 5 represents parts of two different types of

attachment plugs. These pieces must be cheap, fairly strong, unaffected by atmospheric moisture or heat and must take a good finish.

Fig. 6 shows a small switchboard panel. This panel was formed as shown with all holes moulded in.

FIG. 8

Such applications save a great amount of labor when used in large quantities.

Fig. 7 shows a pair of field rheostat face plates, 6.25 and 9.5 in. diameter, made from cold moulded material. Note the number of holes formed and the moulded letters. Moulded letters should be of stocky design and not too high.

Figs. 1 to 7 are typical of the kind of work to which the cold-moulded materials are best adapted. The shapes show what proportions should be maintained to secure a readily mouldable design. The cold moulded compositions can be made into bulky blocks much more readily than the hot moulded varieties. As no heat is required in the forming, no trouble will be experienced due to shrinkage on cooling. With hot-moulded mixtures the material in the mould must be cooled quickly in order to get rapid production. If the piece formed

FIG. 9

is thick and bulky much trouble may be experienced caused by shrinkage strains due to rapid cooling.

DESIGNING OF HOT-MOULDED PIECES

Hot moulding mixtures, that is those formed hot in the mould and hardened before removing, are much better adapted to forming complicated pieces than the cold moulding mixtures. The reason for this is that the binder, when melted, acts as a lubricant to facilitate

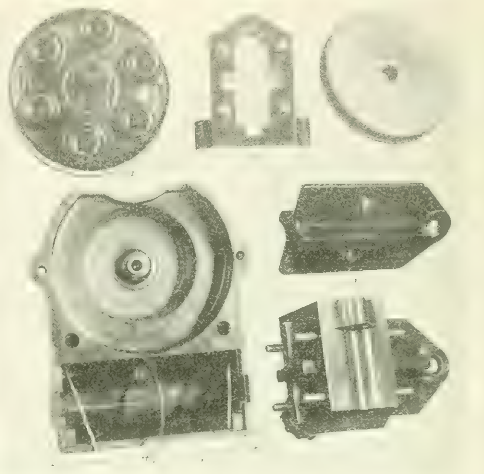


FIG. 10

the flow in the mould and that the binder is hardened and active when the piece is removed. The material, therefore, possesses its full strength to resist breaking while being removed from the mould.

Condensation Moulding—In this class of work, the material first becomes plastic when heated, then

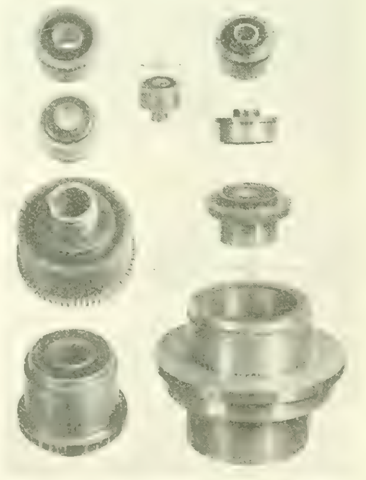


FIG. 11

hardens on continued heating. The material need only to be cooled enough to handle before removing from the mould.

Fig. 8 shows a moulded oil test cup of bulky proportions. It is, for this reason, very difficult to form

and secure a product free from cracks caused by shrinkage strains. It has been accomplished but is expensive owing to the time and care necessary to avoid cracks. This piece has a threaded brass ring moulded in, and a moulded packing box to prevent leakage around the adjustable spark gap sides.

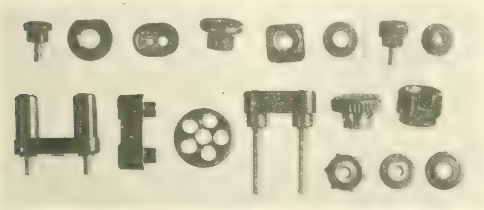


FIG. 12

Fig. 9*a* and *b* shows a hot-moulded, high-voltage circuit breaker bushing and bus-bar support. These pieces also required considerable study before they could be made successfully.

Fig. 10*a* and *b* shows two types of distributor tops for ignition sets. Fig. 10*a* is an easy piece to mould. Notice the taper on all sides, and the uniform thickness of walls, neither too thick nor too thin. The mould is easily made as it is mostly round with few parts to be profiled. Fig. 10*b* includes not only a distributor top but a pocket for the ignition coil. Note the absence of circular sections and the thin portions adjacent to the heavy part. This block has eight brass inserts and three wires moulded in place. The block is being successfully manufactured but is difficult and necessarily expensive. The mould alone cost $1500. In spite of the cost of the block and the tools it is the logical thing to do in this instance, as it gets the desired results in the cheapest way. This is the kind of job on which the designer should consult most freely with the moulder. There are many details, a slight modification of which would render the piece impossible of production.

In Fig. 10 *c, d,* and *e* are shown parts of a reversing switch. The block *d* slides in the shell *e*, the assembled unit being shown in *c*. The mould for the shell piece was costly, but the block is easy to produce.

FIG. 13

These two moulded blocks replaced many metal and insulating parts in the superseded design and materially reduced the cost of the switch.

Fig. 10*f* is a grooved pulley moulded from disintegrated cotton duck treated with phenolic condensation varnish. This makes a tougher product than the usual moulding mixtures. The bearing section is made of a graphitized section to form a self lubricating bearing. This pulley is used in connection with the control wires on airplanes.

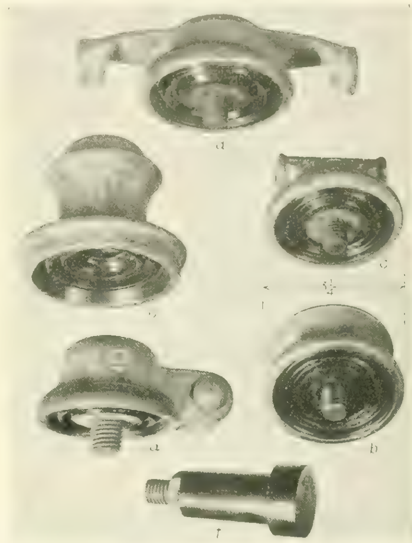


FIG. 14

Fig. 11 represents different forms of moulded commutators. The bars are assembled with mica between and held in the mould while the insulation which replaces the usual front and rear V-rings (both metal and insulation) and the insulation between the bars and the bushing is formed in place. The metal bushing is fastened inside the commutator in the same moulding operation. To get proper mechanical strength without damaging the commutator electrically requires considerable experience and skill. For this work a person experienced in commutator moulding should be consulted in regard to the proportion and shape of all parts.

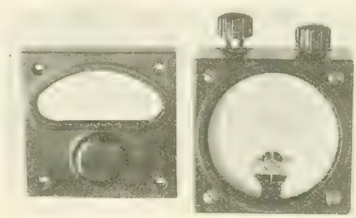


FIG. 15

Fig. 12 shows a collection of simple hot moulded pieces formed "in multiple". That is, they are so designed that many of them, the number depending on the size, can be formed at the same time. This is the best way materially to reduce the cost of a small

moulded block. Here again the cost of the mould interferes and large production is necessary to justify this kind of moulding.

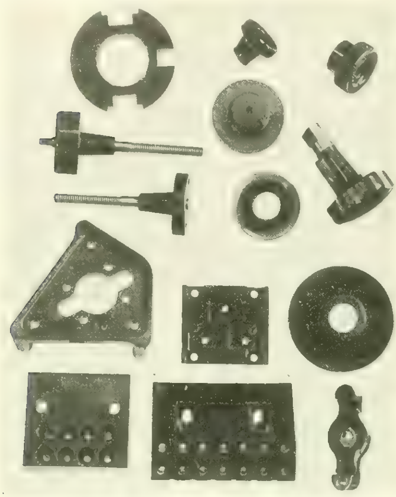


FIG. 16

Fig. 13 is a collection of hot moulded pieces formed singly. Some of these pieces could be made in multiple if sufficiently active. These samples illustrate the variety of designs that can be made, and the shapes that are best suited for moulding.

Shellac Moulded Pieces—Shellac moulding is very much like phenolic condensation moulding except that the material has less strength and a greater tendency to

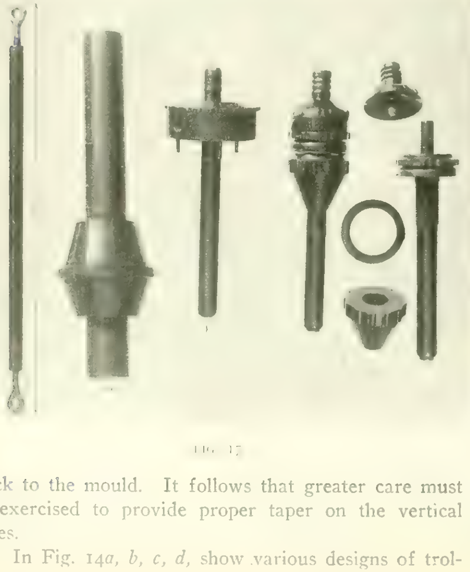


FIG. 17

stick to the mould. It follows that greater care must be exercised to provide proper taper on the vertical sides.

In Fig. 14*a*, *b*, *c*, *d*, show various designs of trolley hangers. They consist of a stud set into a metal shell and insulated from this shell by a shellac moulding mixture. Fig. 14*f* shows an insulated bolt used in another type of trolley hanger. In this case the moulding mixture follows the lines of the metal bolt, the load being carried by the insulated head. Fig. 14*e* shows a

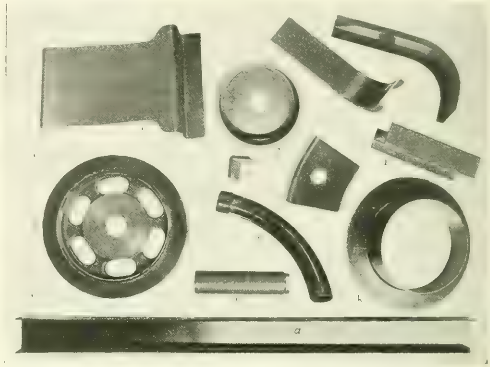


FIG. 18

feeder insulator. The pieces shown in Fig. 16 are formed in multiple. The size of mould for these pieces and therefore their cost will depend on their activity.

Hard Rubber Pieces—Hard rubber moulding is very much like shellac moulding. The comments on the design of shellac moulded pieces will apply as well here. Hard rubber is much stronger than shellac blocks, so it can be made into frail pieces to better advantage. Another difference is that hard rubber moulds must remain in the hot press for a considerable time to permit of complete vulcanization or hardening. It is therefore necessary to form hard rubber pieces in a multiple mould in order to get good production or reasonable cost.

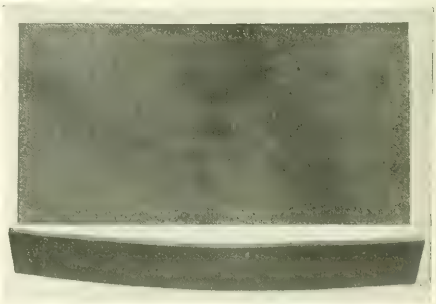


FIG. 19

Hard rubber, moulded to shape, is so common in household use that many examples are not needed. Fig. 15 illustrates meter case parts, a most common use of moulded hard rubber in electrical work.

Micarta Moulding—Micarta is sheet material, either paper or fabric, coated with shellac or phenolic condensation varnish and moulded into flat sheets or

tubes or formed shapes. It is essentially a material of uniform thickness. This class of material is comparatively new and possesses great possibilities. The product is marked by its great mechanical strength and endurance as compared to other moulded insulations.

In Fig. 17, *b* and *c* show pieces in which treated paper is wound around a knurled steel tube and hot moulded to form a micarta tube, while the head is formed of composition during the same moulding operation, the two materials being moulded as a unit. The threads on the stem of *c* are moulded at the same time the piece is formed. The piece shown at *a* is similarly formed of micarta with a moulded collar, except that the micarta is wound on a smooth steel mandrel, which is subsequently removed. The pieces shown at *a* and *b* are designed to serve the same purpose as *c*, and are much more simple from the moulders point of view. Fig. 17*d* is a strain insulator of moulded micarta with eyebolts moulded into the ends. This makes a rugged and light weight insulator for light service, high-voltage work, especially for radio work.

Fig. 9*c* shows stream line shell one sixteenth inch thick, six inches in diameter and 17 inches long. The nose is formed of a moulding mixture. Fig. 9*d* is a bowl with a spherically shaped surface and a shoulder of moulding mixture all formed in one operation. It is one eighth inch thick, 16 inches in diameter and five inches deep. In Fig. 9*e* is shown a ring formed of asbestos paper micarta, duck micarta and a moulding mixture, all three materials being moulded as a unit.

Fig. 18*m* is a brushholder stud with micarta cover moulded around it and closing the rear end. This provides an insulation that can be pressed into its socket, removed and replaced without damage. Fig. 18*m* shows a gear having a metal hub and micarta rim moulded in place to form a noiseless gear. The other specimens in Fig. 18 indicate the wide variety of micarta shapes that is possible. *b* and *c* are formed to fit together to form a rectangular shaped wire way around a corner. *e* shows a similar piece of round section, assembled.

The big feature of this line of materials is its great mechanical strength, as compared to other insulating materials. The merits of this line should be carefully considered by those seeking for high quality products.

Fig. 19 shows a plate made up of alternate layers of cork and fabric, both having a binder of phenolic condensation varnish. This provides a cork plate with considerable strength and one that does not swell with a rise in temperature up to 100 degrees C. It can be made to a variety of densities and is useful as a friction material and as a cushion. Its frictional power is not affected by oil, water and dirt so much as other such materials, as leather, hard fibre, metal, etc.

This article, the first part of which appeared in the March number, was prepared with two objects. The first is to assist the user of moulded insulation to prepare successful designs by acquainting him with manufacturing conditions. The second is to help all engineers to see the great utility of moulded composition, both as insulation and as a mechanical part.

ENGINEERING NOTES

Aim—To connect theory and practice

Measuring the Resistance of Ground Connections

To obtain the resistance of one ground connection, two auxiliary ground connections are necessary, or one of which the resistance is known. In either case the electrodes must be at some distance from each other, the farther the better, but with electrodes of limited extent, such as driven pipes or plates, at least 15 feet for reasonably accurate work. For at 15 feet the mutual influence of the electric fields about two neighboring electrodes can be neglected. And if voltage is impressed upon two of them in series the measured resistance to flow of current from one to the other will be very nearly the sum of the resistance to flow of current away from each one. Hence, if R_1, R_2, R_3 represent the individual resistances, and r_1, r_2, r_3, the resistances of each pair in series, it follows that the equations $R_1 + R_2 = r_1$, $R_2 + R_3 = r_2$ and $R_3 + R_1 = r_3$ are a fair approximation to the actual relationship existing between these various quantities. Solving:

$$R_1 = \frac{r_1 - r_2 + r_3}{2},\quad R_2 = \frac{r_1 + r_2 - r_3}{2}\quad \text{and}\quad R_3 = \frac{r_2 - r_1 + r_3}{2}.$$

For the auxiliary connections, two short pipes temporarily driven into the ground will serve very well. If these pipes are as much as two feet in length, resistances not exceeding 40 to 60 ohms are obtainable in most soils if the surrounding ground is well soaked with water. This resistance will in nearly all cases be found low enough, and in any case the resistance of the auxiliaries may be several times the resistance being measured.

A disadvantage of the foregoing method is that it involves three measurements and considerable computation. In some cases it is practicable to reduce the time and labor required by passing current through two of the ground connections in series and measuring the voltage between the one whose resistance is to be found and a third or potential terminal. The resistance is then calculated simply by substituting in $R = E/I$. Under favorable conditions good results may be obtained in this way. The resistance of the potential terminal must be negligible as compared to that of the voltmeter. This method is especially useful where a ground of negligible resistance (e. g. a fire plug) is available for temporary use as an auxiliary, in which case the unknown resistance may be assumed as equal to the voltage impressed over the two grounds in series, divided by the current.

Alternating current is better than direct current for such testing as with direct current a back e.m.f. of polarization of two or three volts may exist, and the voltage used must be such that the potential drop at each ground will be large enough that the back e.m.f. is negligible in comparison. Usually an accuracy of five to ten percent is all that is desired in such measurements, as the resistance of the grounds is not at all constant.

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

APRIL 1919

Railway Motor Testing—IV

The common practice in a large number of car barns is to take the assembled motors that have been repaired or overhauled and mount them on the cars without final checking, depending upon the tests given the armatures and field coils in the winding room as final assurance that everything is O. K. In some cases, this practice apparently is satisfactory, but to prevent the occasional failures of overhauled cars shortly after being put in service, the following tests should be made on the repaired motors before mounting them on the car trucks.

INSULATION RESISTANCE

Object—It is sometimes advisable to measure the insulation resistance of the electrical apparatus before giving it a ground test, as this test will give an indication of the condition of the insulation. In general, insulating materials are more or less affected by moisture, and if given a ground test while damp, and having a low resistance value, they are more likely to break down than when dried out and having a higher resistance value.

Apparatus—Use apparatus as shown in Fig. 8 in *Railway Operating Data* for January, 1919.

Method—The motor to be tested is connected up to the test line and a reading of the voltmeter is taken which is indicated by d_1 in the formula below. The terminals are then disconnected from the motor and held together while a second reading of the voltmeter is taken, which is indicated by d in formula. A value for r, which is the resistance of the voltmeter, can be obtained from the data attached to the voltmeter. Substituting these values in the formula, $R = r\frac{(d-d_1)}{(d_1)}$ gives a value for R which is the insulation resistance of the motor in ohms. If this value is below 50 000 ohms, it is not advisable to apply the ground test. Insulation resistance can be greatly improved by drying out the motor in an oven.

Precautions—Always use a voltmeter that will measure the maximum trolley voltage on the test line. Be sure that the positive side of the meter is connected to the positive side of the circuit.

GROUNDS

Object—This test is used to locate defective insulation in the commutators, brushholders, wiring-around-frames and windings of the field and armature.

Apparatus—Depending upon the voltage test to be given the motor, use testing outfits as follows:

Lighting-out-line—Limit 500 volts D. C. (See Fig. 4 January R. O. D.)

Insulation test box—Limit to 5 000 volts A. C. (Depends upon the design of box) (See Fig. 1 January R. O. D.)

Method—One terminal from the testing circuit is put on the frame or shaft of the motor while the other terminal is held on the motor leads or commutator, while the current is applied. It is advisable that this test should be for at least 1200 volts on old motors.

Precautions—In making the ground test with the insulation test box, make and break the current by means of the switch on the testing box, and not by the terminals applied to the motor under test. If you make and break the circuit at the test terminals, a voltage kick is produced that may be of such a value as to break down the insulation of the motor.

POLARITY

Object—To check the field coils when connected up in the frame to see that the current is passing around each coil in the right direction. If the main field coils are not properly connected, the motor will operate at a higher speed and tend to take more than its share of the load and overheat the armature. If the commutating-pole field coils are not properly connected, the motor will commutate poorly and tend to flash.

Apparatus—Use apparatus as shown in connection for testing polarity of field coils, Fig. 9, January R. O. D.

Method—The current is passed through all of the main field coils connected in series and by means of a compass needle held to the same end of each coil or to the bolts or studs holding the poles to the frame, the polarity is checked by noting which end of the compass needle is attracted by the coil. Adjacent coils should attract opposite ends of the compass needle. A separate test should be made on the commutating-pole coils. For more complete details of this method, see R. O. D. December, 1916.

RUNNING TEST—ON FLOOR

Object—To check the condition of the motor bearings while the armature is rotating. This test also gives an indication of the running balance of the armature.

Apparatus—Testing circuit to run motor as shown by Fig. 10 in January R. O. D.

Method—With the motor on the floor, connect one lead of the armature to a field lead, and the other field and the other armature lead to the two terminals from the testing circuit. With the circuit breaker closed, move the control handle to the *on* position until a safe speed (approximately 1500 to 2000 r.p.m.) is obtained. Run at this speed for at least five minutes and note the condition and temperature of the bearings. Any bearings which show rapid temperature rise should be adjusted before being put into service. Also note the amount of vibration while the motor is running. If the vibration is considerable, with a tendency for the frame to creep on the floor, the armature is out of balance and the motor bearing wear will be excessive.

Precautions—Be sure to see that the bearings are properly packed and lubricated before starting the test. See that carbon brushes are in place. Do not exceed the dangerous speed limit of the armature, which is found by dividing the safe allowable peripheral speed of the armature core, (which may be assumed to be 7 000 feet per minute) by the circumference of the armature core in feet.

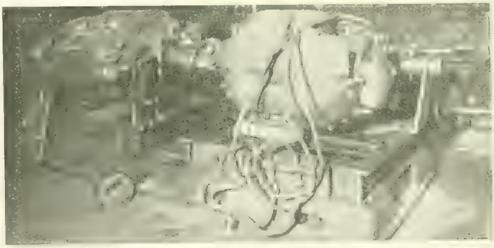


FIG. 19—MOTORS COUPLED FOR RUNNING LOAD TEST ON FLOOR. THE MOTORS MUST BE SECURELY BOLTED DOWN DURING THIS TEST

SPECIAL TEST ON FLOOR

Other running tests that are sometimes made on motors after being repaired are load tests to determine any wrong connections of the windings; also to locate any defects in the soldering of the armature and field windings. In making these tests, two machines are coupled together, one used as a motor to drive the other which is used as a generator to furnish the load, as shown in Fig. 19, the generated current usually being used to help drive the motor by the "loading back method."

RUNNING TEST ON CAR

Object—To check the connections of motors to the car wiring, after they are placed on the trucks under the car. This test is necessary to make sure that all of the motors when taking current from the trolley, rotate in the same direction and pull together.

Apparatus—The regular car equipment.

Method—One pair of motors on a quadruple equipment, or one motor of a double equipment are cut out and with the controller on "forward" position, the wheels of the motors in the circuit are spun (a little water on the rail will aid this slipping), and the direction of rotation checked and made to correspond to the position on the controllers. This operation is repeated for the backward position of the controller as a further check. In a similar manner, the other motors are checked.

Precautions—In making these tests, be sure there is sufficient clear track at both ends of the car to allow for a short travel of the car. Ring the bell to warn other workmen. Be sure the brakes are properly adjusted.

J. S. DEAN

THE JOURNAL QUESTION BOX

OUR subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. The topics should be of general interest; information involving the specific design of individual pieces of apparatus is not supplied. Care should be used to include all data necessary for an intelligent answer.

A PERSONAL reply is mailed to each questioner enclosing a stamped, self addressed envelope as soon as the necessary information can be obtained. Anonymous questions cannot be considered. As each question is answered by an expert on the subject involved, and checked by at least two others, a reasonable length of time should be allowed before expecting an answer.

1724—GENERATOR COMPOUNDING—What is the approximate ratio of the shunt field ampere turns to the series field ampere turns in say a 50 kw, compound winding direct-current generator? H.R.L. (PA.)

The series field ampere-turns in a 50 kw, direct-current generator range from 25 to 50 percent of the shunt field ampere-turns. The proportion increases with the amount of overcompounding required, and generally is larger in a low-speed machine than in a high-speed machine. F.L.M.

1725—SINGLE-PHASE MOTOR WINDING—I have a two horse-power, six-pole, repulsion starting single-phase motor. The commutator has 81 commutator bars and the rotor has 82 coils. I was instructed to wind with lead pitch of *1* and *28* retrogressive winding. Am I right when I say that a lead pitch of *1* and *28* will short-circuit itself the first time around, as the leads will fall in slots 1 + 28 + 55 + 82. To be retrogressive the winding leads should fall 1 + 27 + 53 + 79 which will leave two extra bars between 79 + 81. T.S. (CAL.)

The term "lead pitch" is sometimes used. "Lead throw" or "lead span" would be better. An 81 bar commutator cannot be wound for six poles using two circuit or wave winding and utilizing all bars. In this case, connect the leads to bars 1 and 28. Connect any two adjacent commutator bars together and consider the commutator as having 80 bars. This will leave two dead coils which should not be connected to the commutator. In this type of motor it is immaterial whether the winding is progressive or retrogressive. G.H.G.

1726—BLUE COMMUTATOR—What could cause the commutator to get blue on a 90 hp, 500 volt direct-current crane type motor? There is no sparking at the brushes and the motor is not overloaded. Could I use 110 volts, direct-current for lighting on a coal crane and ground the negative line on the same circuit with 600 volts direct-current with the negative grounded and use the positive on a trolley line? Could I use 110 volts single-phase alternating current for lighting on a coal crane and ground one line on a 600 volt grounded circuit and use the other line for a trolley? A.R.H. (WIS.)

The commutator may be worn down to such an extent that the brushes cover too many commutator bars, or the brushes may be wider than they should be for this machine, thereby causing extensive heating in the brush faces due to the current in the coils short-circuited by the brushes. Or there may be partial short-circuits between commutator bars due to failure of the insulation or to dirt or oil, causing excessive current to flow through the commutator. (b) It is perfectly feasible to ground one side of two or more circuits on the crane, regardless of the voltage and kind of current. J.M.H.

1727—REVERSAL OF EXCITER VOLTAGE—The electrical equipment in question consists of a large turbogenerator, a direct-connected exciter and a voltage regulator for controlling the exciter voltage. The regulator was not operating properly and the operator, wishing to take it out of service to adjust it, proceeded in the usual manner. Before he got the regulator out of service, however, the exciter voltage dropped rapidly, the generator being connected to its load all the while. The exciter voltage not only dropped to a point proportionate to the shunt field rheostat setting, but continued falling to zero and then it built up in the reverse direction, that is, the exciter polarity became reversed. Shortly afterwards the writer was watching the switchboard while the operator went to the basement to adjust the exciter shunt field rheostat, the control voltage at the time being too low to operate the magnetic controllers on the rheostat. The operator intended to raise the exciter voltage but by mistake turned the rheostat in the wrong direction and low exciter voltage again resulted. The exciter voltage again fell to zero and again built up to normal voltage of reversed polarity that is the exciter polarity was reversed a second time, which of course left it with the correct and original polarity. This second reversal also took place while the generator was connected to its load. The question is, what reversed the exciter polarity. Is the writer correct in the following explanation? The low exciter voltage caused a corresponding low alternating voltage and the resulting high load current. This high load current induced in the alternator field a pulsating current which flowed in a closed circuit through the exciter armature and fields, and flowing through the series fields in the reversed direction, it reversed the polarity of the exciter. The exciter then built up to normal voltage, but with reversed polarity, and the alternator assumed normal voltage and normal load current. R.M.H. (PA.)

The following possible explanation of the phenomenon described is based on the supposition that the series field is weak, or the brushes are rocked forward considerably, to such a degree that the demagnetizing component of armature reaction is stronger than the series field. Suppose a large portion of the exciter shunt field rheostat is cut in. The exciter voltage begins to drop, but due to the high inductance of the turbogenerator field, the exciter load current holds up. Consequently, when the exciter voltage and shunt field current have reached a very low value, the armature current may still be fairly large, and may overpower the shunt and series fields, thereby reversing the flux in the machine. This results in reversal of the exciter terminal voltage, permitting it to build up again, but with the opposite polarity. F.L.M.

1728—ELECTROLYTIC MANUFACTURE OF OXYGEN—What is the direct-current voltage applied to electrolytic cells for generating oxygen from water so as not to raise steam or mist? How much sulphuric acid to each gallon of water? What other salts or chemicals can be added to the water as a carrier of current and how much to the gallon of water? I want to use oxygen for experimental purposes and the use is intermittent and I want to get all the oxygen that the cell or cells are capable of delivering. There are about five gallons of water per cell. I have a 12 volt generator with a capacity of 50 amperes. L.T.A. (TENN.)

The voltage required for electrolytic cells for generating oxygen from water would probably be 2.5 to 3 volts per cell. A current of about 20 amperes per square foot of electrode could probably be used without raising an objectionable amount of steam, although this depends largely on the design of the cell. A 20 percent solution of sulphuric acid would probably give about the proper conductivity, although this could best be determined by trials. However, in electrolytic cells an alkaline solution is often used, as this is more efficient. About 15 percent caustic soda or 20 percent caustic potash is the strength usually used. With an acid solution, lead plates are used, while with an alkaline solution iron plates are used. The iron anodes would have to be renewed occasionally owing to traces of chlorides, which would render them non-passive. A well designed electrolytic cell will require from 13 to 15 kw-hrs. per cubic meter of oxygen generated. The ventilation of a room where electrolytic cells are located should be very good, as otherwise an explosive mixture of oxygen and hydrogen might result from leakage. The cell should also be designed so that there is no danger of the gases mixing as they are generated. C.H.M.

1729—RECONNECTING ROTOR—In reconnecting a slip ring motor for a different voltage, is it necessary to change the rotor connections to parallel or series circuits corresponding to the stator connections, raising or lowering the voltage as the case may be? It is my opinion that it is not necessary. B.C. (IND.)

It is not necessary to change the rotor connections in changing the stator connections for a different voltage. This is due to the fact that the volts per conductor which induce the voltage in the rotor conductors are not changed

within narrow limits when the change in the primary is made. B.B.R.

1730—No-Load Conditions of an Induction Motor—What current should a 100 hp, 3 phase, 60 cycle, 550 volt motor, 98 amperes per terminal and 700 r.p.m. draw running light, that is, with no pulley on the shaft? Would the autotransformer starter for the above motor normally have a humming sound and apparently draw current from the line when thrown to the starting position with motor leads open? R.O. (GA.)

A squirrel-cage motor of this rating will require approximately 40 amperes per phase when running light. This value will vary in motors made by different manufacturers. The autostarter, when put on the starting tap, may hum the same as any transformer when put on the line, and will take current from the line for magnetizing the iron. C.W.K.

1731—Parallel Operation of Compound Exciters—In operating compound wound exciters in parallel, with the positive switch controlled by one pull button switch and the negative and equalizer by another pull switch, what is the proper sequence to close switches when wishing to put on a second exciter, the positive switch first or the negative and equalizer, when regulation is by Tirrill regulator? In connecting a Westinghouse type *D* reverse current relay in the leads to the exciters, which switch should it be set to trip when the negative and equalizer work together and the positive separate? E.E.S. (OHIO)

We recommend closing the negative and equalizer switch first, thus permitting the series field to be built up first. This method should give less disturbance to the system than would be the case if the positive switch is closed first. This method should be followed irrespective of whether there is a regulator or not. If trouble is experienced on account of the use of the voltage regulator, it is due to the manipulation of the exciter rheostats. The reverse current relay should preferably be connected to trip both the negative and equalizer circuit breaker and positive circuit breaker. In case only one can be tripped, the negative and equalizer switch should be brought out. H.A.T.

1732—Design of High-Voltage Transformers—Is it possible to construct a high-tension transformer which will give a very high voltage, but an insignificant amount of current. What is wanted is a transformer to step up 110 volts, 60 cycles to 20 000 or 40 000 volts. This secondary is wanted to excite Crookes Tubes, but the secondary current must be kept very low. The idea is to get an effect something like an induction coil, or a static machine. I have attempted to use a transformer in the ordinary way, but the tube suddenly heated up to an excessive point. I also tried by putting a reactance in series with the primary, but this seemed to cut down the voltage also. This transformer stepped 110 volts up to about 7 500 volts. The primary is wound with No. 18 wire, and the secondary with No. 35. The iron is run at about 30 000 lines per sq. in. What would be necessary to obtain the above desired result, if it is possible? N.J.V. (CALIF.)

It is possible to construct a transformer that is suitable for exciting Crookes Tubes but they are not as suitable for that service as an induction coil. A transformer for this purpose should have high reactance, that is, it should have a large leakage flux between primary and secondary. This can best be obtained by making the transformer core type and winding the primary on one core leg and the secondary on the other. J.F.P.

1733—Magnetic Center of Generator—I would like to know the proper method of determining the magnetic center, that is the point which the rotor will assume if allowed to find its own center of a 1500 kw, three-phase, 1800 r.p.m. steam turbine-driven alternating-current generator. Can it be found by measuring the iron of the rotor and stator and if so, how much could the center line of the rotor iron be out from the center line of the stator iron, when the stator iron measures 8 ft., 0.75 in. and the rotor iron 8 ft. outside to outside measurements? If the generator were run as a synchronous motor and allowed to find its center would that be correct for the generator under full load? E.E.S. (OHIO)

In assembling a turboalternator, the vertical center line of the stator iron should be lined up with the center line of the active iron of the rotor and the rotor will then be in its magnetic center, provided the flux density is equal on both ends of the machine. Unequal flux densities on either side of the center line may be caused by the iron being built up tighter on one side than the other, and result in a thrust which will throw the centers out of line when running, but this movement is so slight that it can be taken care of in the play of the bearing. If both bearings are at the same elevation, the rotor will find its true magnetic center when the machine is run as a synchronous motor, and will not change between no load and full load. Usually, however, the two outboard bearings of a turbine-driven unit are slightly elevated in order to bring the two faces of the coupling parallel to each other, and in this event, if the generator were run as a synchronous motor, the rotor would drift toward the inboard bearing and away from its magnetic center. S.L.H.

1734—Armature Winding of Universal Motor—On winding small direct-current and universal machine armatures, I have met with a peculiar phenomenon which I would like to have explained in a simple form. On several occasions in trying to connect the winding to the commutator, I was unable to find a definite neutral point, as I understand the leads connecting the commutator bars directly under the brushes should come from the coil spanning one pole piece; that is both halves of the coil lying in the armature slots which are between the pole tips of adjacent poles should be connected to the before mentioned bars, but I found that this rule does not hold true on this small machine. Please explain how to find the proper bars to which to connect the coils, providing the span, size of wire and number of turns and everything is in strict accordance with the designers specifications. F.S. (OHIO)

Small commutating armatures are frequently operated with the brushes not on the neutral point, which is probably the cause of the difficulty. A great many of the small universal motors, which resemble the usual direct-current design with laminated fields, are operated with the brushes located some distance back of the neutral point. No general rule can be given for the amount of shift, as this would depend entirely upon the design and the results desired. In rewinding a machine of this type, the only safe rule to follow is to observe carefully the throw of the coils and the connection to the commutator used in the original machine and connect the new winding in the same manner. One other point which may have caused confusion is the fact that generally these small armatures are wound with a coil span slightly less than the number of slots divided by the number of poles. This is generally done to facilitate winding and save end room. On such windings the neutral point is at the location of the coil ends on the commutator when the two sides of the coil are located equal distances from the center of the pole face. G.H.G.

1735—Arc Welding—In the September Journal is an instructive article on arc welding, from which it would appear that it is necessary to have a special generating outfit for this work. I would like to know if it is not practicable to use the regular 240 or 120 volt lines in the plant as long as they have abundant capacity. Also how would I figure the right sort of resistance and reactance to do this? Is it possible to weld rail bonds from a 240 volt direct-current trolley wire with resistance only in series with the arc? R.W.B. (MICH.)

There are several objections to the use of a resistance connected to a 120 or 240 volt direct-current circuit for arc welding. However, it is entirely feasible to perform the work by this means and, in the hands of an experienced welder an entirely satisfactory weld can be made upon materials and shapes which are suited to repair and fabrication by the arc welding process. For general arc welding work, the use of the metallic electrode process will result in much more satisfactory welds than the use of the carbon electrode. Therefore, the metal electrode only will be considered. The potential drop across the metallic electrode arc should be maintained by the operator at a value of 20 volts or less, if possible, and never above 25 volts for momentary periods. Where constant potential circuits are used for supplying power to the arc it is necessary to have a resistance in series with the electrode to stabilize the arc. Actual experience has proven that a 60 volt potential is sufficiently high for this service. It is obvious, therefore, that when power is supplied by a 120 or 240 volt line the losses in series resistance are increased, thereby decreasing the efficiency and economy of the welding work. Furthermore, with such a high open circuit potential available it is possible for the operator to maintain an extremely long arc having a potential drop of as high as 35 to 40 volts, or possibly higher for momentary periods. This will result in

lack of penetration of deposited material and also porosity and oxidization of the surface of the deposited material. These undesirable effects can be eliminated by a conscientious workman who will continuously maintain a short arc of 20 volts or less. With a 120 or 240 volt circuit it is unnecessary to make use of a reactance in addition to the resistance, especially in the case of the higher potential, because the arc voltage is a relatively small percentage of the line voltage. Therefore, the increase of current when the electrode is touched to the work will not be appreciably greater. Theoretically, in the case of the 120 volt line potential and a resistance designed for 20 volt arc the increase of current upon short-circuiting the electrode would be 20 percent approximately, whereas, in the case of the 240 volt circuit the increase of current theoretically would be nine percent approximately. To compute the proper amount of resistance for a metal electrode welding circuit the potential drop across the resistance should be based upon 100 volts in case of a 120 volt line and 220 volts in case of a 240 volt line. For all-around welding work, the resistance should be designed so that the current flowing may be varied between the limits of 25 amperes minimum to 225 amperes maximum. Owing to the difference in the fusing temperature of copper and steel rails it is very difficult to arc weld copper bonds to steel rails. This work is probably best accomplished by means of one of the resistance welding devices, a number of which are on the market and available for this service. It has been the practice of several mine operators, however, to eliminate the copper bonding of the rails and resort to arc welding the fish-plates or rail joints directly to the rails at each end of the plate or joint, making use of the metallic electrode process. A.M.C.

1736—FLUCTUATING LOAD—The writer has a 500 kw and a 150 kw, six-phase, 60 cycle, 250 volt rotary converter. The 250 volt machine is used for elevators and the load averages from three second readings about 500 amperes. The amperes go with just a swing of the needle and back up to 1000 amperes about once in five minutes but most of the time stay swinging from 300 to 600. The converters are of the commutating pole type, and consequently should stand at least 900 amperes on the 150 kw but the circuit breaker is set at its limit of 950 and flies out, hence we have to operate the 500 kw on an average of one-quarter load. Now I would like your opinion as to the idea of placing a choke coil in the feeder from the 150 kw to choke down to say 900 amperes when it would go to 1000 or 1100 and if this would work, the little machine of 150 kw could be run and be quite a saving. Would there be any undesirable effect, or in the starting of the elevator, would they just start a little slower? The excess current is due to a number of elevators starting simultaneously. Would you advise a reactance coil with or without iron? J.E.M. (MICH)

Upon starting an elevator, the current in the motor armature rises rapidly to its maximum, as limited by the first resistance step. An instant later, the car starts, and as the car speeds up and the counter e.m.f. of the motor builds up the current decreases. Therefore, to limit the maximum value of current drawn from the converter, when the elevators are started, by means of a choke coil, as you have suggested, the inductance of this coil must be sufficient to keep the current from reaching its maximum value before the car starts. Oscillograms taken of the armature current of elevator motors starting under normal conditions show that the armature current rises to its maximum value, as limited by the first resistance step, in a small fraction of the time required for the car to start moving. Therefore, it is evident that a choke coil of considerable inductance will be required. On one of the elevator systems of a hotel in one of the large cities, considerable trouble was experienced due to sudden jerks and too rapid acceleration of the elevator motors with subsequent wear and breaking of the cables. This was remedied to a large extent by the use of a choke coil in the armature circuit. The oscillogram taken in connection with this test showed that the rate at which the current increased was materially reduced by the use of the inductance coil, but did not keep the current from reaching its final value before the car started. Assuming that the maximum current peak is due to several elevators starting simultaneously, as you have suggested, calculations based on the above tests indicate that an inductance of at least 0.08 henry will be required to limit the current peak to the desired value of 900 amperes. A coil of this inductance wound on an iron core (which would be the cheapest) and having sufficient current-carrying capacity will probably weigh several times as much as the 150 kw converter. Therefore, the use of an inductance coil to limit the peak value of the current drawn by the elevator motors is out of the question. However, a reasonable amount of reactance, as shown by the above mentioned test will smooth out the acceleration of the car and limit the current peaks to a small extent, due to the various steps in the control system. Hence, if the current peaks which open the circuit breaker are partially due to rather sudden increases in the current caused by some peculiarity in the control circuit, a reasonable amount of inductance might be of some value in holding down the peak value of the current. If the current peak is caused by several elevators starting simultaneously and if the total amount of current as limited by the resistance in the first step of the control (which is not usually the case) is required to start the car, an inductance would not do any good, for the car would not start until the current had reached its maximum value. If there is a large margin between the current drawn on the first step of the control and that actually required to start the elevators, the current peak could be limited by inserting a higher resistance in the control circuit upon starting the car. Assuming the r.m.s. value of the current is within the limit of the 150 kw converter, so far as heating is concerned (which is apparently so from the values of current you have given) the machine should be able to stand the momentary overload of 1000 to 1100 amperes. Therefore, if there is no other reason for limiting the current peak than to bring it with the limit of the present circuit breaker, it seems that the most logical and inexpensive thing to do would be to install a new circuit breaker of sufficient capacity to handle the current. M.W.S.

1737 — WEDGES FOR ARMATURES — We have had considerable trouble with wedges for direct-current motor armatures. At present we are using fibre wedges but find that they occasionally carbonize and become loose, so that the coils are thrown out. Please advise what other material has been used for this purpose. What would be the effect of metal wedges, such as steel, brass or aluminum? E.H.A. (WIS.)

Our experience is that fibre does not carbonize at temperatures materially below 105 degrees C. and all motors of the present day are designed to work below that point. Fibre is probably the best material for direct-current armature wedges. However, there are different grades of fibre and only the best grade is suitable for wedges. Metal wedges, if made of brass or any other non-magnetic metal, give fairly good service if they can be insulated properly from the armature iron. Steel, iron or any other magnetic metal cannot be used for wedges for commutation reasons. Such magnetic wedges would cause such very high reactance in the armature that the commutation would be poor. Wooden wedges give fairly good results but they are hard to put in the armature slot if cut across the grain, and they split easily if cut along the grain. F.J.A.

1738 — RECONNECTING DIRECT-CURRENT MOTOR—Sometimes it is convenient to change the voltage of a single series-wound armature say from 500 to 250 volts by reconnecting the commutator, making a double series winding, assuming of course that such connections are changed properly in the commutator and also that the proper voltage field coils are used giving the same magnetic density in each case. What is the proper analysis to make to determine beforehand whether the machine will or will not commutate properly? In cases of armatures with four coils per slot (two top and two bottom) and six coils per slot (three top and three bottom) is there one of them that cannot be reconnected for one half original voltage on account of the mutual or self induction of inductors in the slots? R.L.B. (OHIO)

A detailed analysis of single and double series windings cannot be made brief enough for reply to the above question, but some general statements will be made which will indicate whether a given machine will commutate properly with single or double series winding. (a) A double series winding should have such a number of slots and commutator bars that equalizer connections from one winding to the other can be connected to equal potential points. (b) To obtain condition (a) the total number of commutator bars must be a multiple of half the number of circuits and the number of poles must be a multiple of the number of circuits (single series having two circuits and a double series four, etc.) If conditions (a) and (b) are met the commu-

tator connections for the double series winding can be made and equalizers added without making commutation any worse. It is not advisable to make the change unless the equalizers are used. The number of coils per slot should have no effect on commutation with the above change. A single series progressive winding may be connected for double series by taking the top lead out of its commutator bar and setting it in the next bar back. Another method of reconnecting a single series winding for half voltage is to connect the commutator bars together in pairs (with solder if a small machine but with a copper jumper if the machine is large). Before reconnecting, the winding should be changed to a double series winding and bars to be connected in pairs must have their corresponding conductors lying in the same slot. If they lie in different slots short circuit currents will be generated, causing excessive heating of the armature winding. It follows, therefore, that this scheme cannot be used where the number of coils per slot is not a multiple of 2. It should be understood that the commutator capacity will limit the rating when the voltage is cut in half, but with above connection a wider brush may be used so the new rating will be something more than half that with full voltage. Mutual and self induction will not prevent reconnecting the armature for double series winding.

E.M.C.

1739—BATTERY CAPACITY OF ELECTRIC VEHICLE—How do you determine the size of motor or motors and battery to propel an electric vehicle. For example, total load of car, including weight of car, three tons at ten miles per hour. C.A.K. (N.Y.)

The data supplied is rather indefinite, so that a general reply only can be made. If the vehicle is equipped with rubber tired wheels and the vehicle is of the commercial classification, the horsepower required to propel a vehicle may be obtained as follows:—

Let Hp = Horsepower output of motor. W = Weight of vehicle and load in tons. R = Resistance of traction of vehicle in lbs. per ton. For rubber tired vehicles on hard level asphalt, this will vary from 20 to 40 lbs. per ton. 35 lbs. per ton will be a safe value to assume. v = Speed of vehicle in feet per minute. V = Speed of vehicle in miles per hour. e_t = Mechanical efficiency of transmission from armature shaft to rim of wheel, assumed as 85 to 95 percent, 90 percent being an average value. e_m = Efficiency of motor, may be safely assumed at 85 percent. E = Voltage at motor terminals, usually assumed as 80 to 85 volts for 40 to 44 cell lead acid battery and 60 to 65 volts for 60 cell Edison battery. I = Normal continuous rating of motor in amperes.

Then,—

$$Hp = \frac{W \times R \times v}{33000 \times e_t} = \frac{W \times R}{33000 \times e_t} \times \frac{V \times 5280}{60} = \frac{W \times R \times V}{375 \times e_t} \ldots\ldots (1)$$

Substituting value of e_t as 0.90,—

$$Hp = \frac{W \times R \times V}{375 \times 0.9} = \frac{W \times R \times V}{337} \ldots (2)$$

$$EI = \frac{Hp \times 746}{e_m} = \frac{W \times R \times V \times 746}{337 \times e_m}$$

$$= \frac{2.22\ W \times R \times V}{e_m} \ldots\ldots (3)$$

Substituting value of e_m, as 0.85,—

$$EI = \frac{2.22\ W \times R \times V}{0.85} =$$

$$2.6\ W \times R \times V \ldots\ldots\ldots\ldots (4)$$

$$I = \frac{2.6\ W \times R \times V}{E} \ldots\ldots\ldots\ldots (5)$$

In making applications of motors to electric vehicles, the rating of the motor is generally estimated on the basis of the operation of the vehicle on hard level asphalt, hence for a rubber tired vehicle weighing three tons loaded and operating at a speed of 10 miles per hour, the horsepower of the motor may be calculated by making substitutions in equation *1* as follows,—

$$Hp = \frac{3 \times 35 \times 10}{337} = 3.11$$

Since vehicle motors are given a continuous rating on the basis of current input in amperes at a specified voltage and speed, the current rating of the motor for the vehicle under consideration may be calculated by making substitutions in equation (*5*) as follows,—

For 80 volt operation I =

$$\frac{2.6 \times 3 \times 35 \times 10}{80} = 34.2 \text{ amperes}$$

For 60 volt operation I =

$$\frac{2.6 \times 3 \times 35 \times 10}{60} = 45.8 \text{ amperes}$$

The speed of the motor will be dependent upon the total speed reduction between the armature shaft and the wheels and upon the diameter of the driving wheels. The speed reduction and the diameter of the wheel are usually chosen by the vehicle manufacturer to be such as to enable him to apply standard motors of the vehicle type, the speed of which will be approximately 1200 to 1500 r.p.m. The manufacturer then selects that standard motor which will most nearly approximate the rating as calculated, which for the present example would be for lead battery operation, 80 volts, 35 amperes, 1500 r.p.m. and for Edison battery operation 60 volts, 47 amperes, 1500 r.p.m. In order to make a detailed analysis of the application of the motors to vehicles, it would be necessary to have complete data regarding the vehicle design and the conditions under which it is to operate. However, in general the approximation as outlined will be found to be satisfactory. The energy consumption and therefore the battery capacity, is dependent on,—

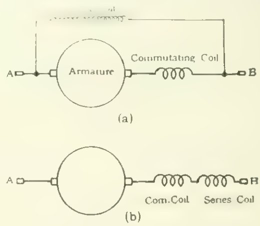
1—Efficiency of the battery, motor and transmission.
2—Tire equipment.
3—Nature of roads and grades.
4—Number of stops.
5—Radius of operation required for single charge.
6—Intelligence of the driver; for example, to coast instead of braking directly from full speed when making the stop.

The electric vehicle manufacturers have in general determined from experience the battery capacity required for a vehicle having a given load capacity. A vehicle of the size suggested would be equipped with a battery having a rated capacity of approximately 13 to 17 kw-hrs.

J.G.C.

1740—TESTING POLARITY OF COMMUTATING POLES—What is the best and simplest method of testing for correct polarity the commutating poles of direct-current generators and motors either shunt, compound or series wound? T.B. (CAN.)

The final test of the commutating coil is the commutation. In the case of a shunt or compound-wound motor or generator, or of a series generator a simple method of testing for the correct polarity of the commutating coils is to start the machine at no load and gradually load. If the machine can be brought up to full load with anything near satisfactory commutation the coil has the right polarity. In case commutation becomes very bad the connections of the commutation coil with respect to the armature can be reversed and the gradual loading up tried again. A comparison of the commutation in the two cases will show which was correct. In the case of a series wound motor this method cannot be used, as a series wound motor will probably over speed at no load. In this case we would suggest a checking of the wiring rather than a test. In any motor, series, compound or shunt wound, any main pole and the next following interpole, in the direction of rotation, should have the same polarity. In the case of any generator the polarities should be opposite. The polarities of the poles are sometimes tested by suspending a small piece of iron, as heavy iron wire, by a thread around its center, marking one end, suspending the iron near the



FIGS. 1740(a) and (b)

back of a main pole, noting which end of the iron is most strongly attracted to the pole, and then moving the iron forward to the next interpole and noting which end is attracted by it. If the same end is attracted by both poles, the polarity of the poles is the same. In Figs. (a) and (b), A and B are the line terminals. Fig. (a) represents a shunt or compound wound motor or generator. In Fig. (b) is represented a series motor or generator. When tracing the wiring from A to B, or vice versa, in case of a shunt or compound-wound motor or generator, the shunt conductors and the commutating coil conductors should lead around any main pole and the next following commutating pole in the same direction, for correct polarity. The same is true in Fig. (b) for the series coils and the next commutating coil on a series motor, but they should go around in opposite directions on a series generator.

M.S.H.

CORRECTION

The equation in question 1713 (March '19) should read: *Volts drop* = 10.7 × *amperes × the entire length of wire in the circuit in feet ÷ the circular mils.* The second sentence following should be omitted.

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The National Electric Light Association for 1919

W. F. WELLS
President,
National Electric Light Association

THE FIRST convention of the National Electric Light Association was called some thirty years ago so that the men engaged in the electric lighting industry could get together, and in an open forum discuss ways and means of advancing the art and science of the production, distribution and use of electricity for public service, and of overcoming the difficulties incident thereto. A few men attended this first convention. The amount of capital investment they represented was small and the securities of the industry were considered highly speculative by the investing public.

W. F. WELLS
Vice-President
Brooklyn Edison Co.

That the objects of the Association have been attained in a remarkable degree and that the industry has developed and assumed an importance, then probably undreamed of, has been evident to all during the past few months. The member companies, engaged principally in lighting in the early days, have developed into the great public utilities of today serving the public for miles around not only with light, but with power adaptable for every purpose from the one-eighth kilowatt used by the jeweler to thousands of kilowatts used by shipyards, steel mills and countless manufacturing plants. Our advancement in the art and science of the production and distribution of electricity has made it possible to locate factories with regard to the source of raw material, the consumption of the product and the environment of the employes. We have made it unnecessary to locate the mill by the stream, the foundry near the charcoal pit, or the ice house by the pond.

During the war, it was the power supply developed by the members of our organization that helped in great measure to make possible the rapid erection and equipment of factories, shipyards and war supply bases for the production and transportation of the supplies required to send two million men overseas within a year. Our importance was recognized by the Federal Government which granted us priorities in obtaining our coal and equipment needed in the extension of plant. We must now "beat our swords into plowshares and our spears into pruning hooks" for our power is needed for producing farm tractors instead of tanks; it is required for sewing machines instead of machine guns.

The greatest developments of our age have come through team work and perfected organization. The founders and leaders of our Association realized this and long prior to the war had developed an organization and worked out a plan whereby representatives of member companies could learn from others by the interchange of views upon every subject pertinent to the industry. This plan provided for formal assemblies at conventions, meetings of committees appointed for investigations of special subjects and the acquaintanceship of members which makes possible intimate conferences upon any detail of our industry by people particularly interested therein.

During the war our educational activities were curtailed but our country profited by the knowledge previously disseminated by our Association, through enlistment and induction into military and naval service of many of our members for duty here or overseas, as well as through commandeering or utilizing the personnel, plants and power supply of our member companies.

Now that the armistice has been signed, our activities have been resumed. Committees are at work and on May 19th, 1919, our Forty-second Convention at Atlantic City will again take up for consideration the subjects leading to the fullest development of the electrical engineering arts and sciences in all their branches and the problems incident to the readjustment and establishment on a peace time basis of an industry in which is invested some three billions of dollars.

Immediate Economic Aspects of the Electric Supply Industry

J. D. MORTIMER
President,
North American Company

THE ELECTRIC light and power utility industry has suffered the least of any of the municipal utilities during the war period. The energy output of electric utilities in practically all cases showed large increases and the growth of the business went some distance toward offsetting increased costs of service. Few electric utilities, if any, received in revenues the current costs of delivering service, but existing capacities were in many instances utilized to their utmost limit, and in violation of previous notions of safe engineering practice. Overload on production and distribution plant permitted greater output with practically stationary investment. The usual increases in capacity were impossible because of lack of equipment and difficulties of finance. The investment status of the industry also suffered by sympathy with other utilities and the rising cost of money depreciated

market values of outstanding securities. The practices hazarded during the war, permitted the business temporarily to keep its head above water. Substantial replacements and increases in equipment are now necessary for the industry to hold its own; and the increased demand for service which will come with permanent peace requires a large amount of new capital.

Unstable returns are the bain of the privately-owned utility business. Rapidly changing costs have shown the advantages of automatic regulation of rates. Contracts for the sale of large quantities of electric energy containing a formula for varying the resultant rate in accordance with the load factor and power-factor, were accepted by the industry many years ago. Contracts with formulæ for determining the rate in accordance with the variations in two or three important cost factors are now becoming more generally acceptable to both the utilities and the customers. Complete automatic regulation cannot be had through the use of such rate schedules, but the disturbances in resultant rate can be minimized by the use of such schedules.

The high costs of production have convinced more people than ever before that there is comparatively little speculative value in the public utility business. The sooner that this fact is generally recognized, the more stable will the business become and the greater will be the opportunity for expanding it to meet the requirements of the districts served more generally by obtaining money at lower annual cost.

Aside from fixed and investment charges, the two largest single items in cost of service from steam-driven plants are coal and labor. A large reduction in the price of coal is not to be expected unless the mines are to be required to operate at less than a reasonable profit or some new method is discovered for mining coal which will largely reduce the cost thereof. Reduction in electric generating costs will then necessarily come from improvement in power station equipment and from better utilization of, and through improved load factor on, existing apparatus. Monthly rates for labor are not likely to be reduced. It is a questionable wisdom to contemplate a reduction in wage rates, even if such were possible, under a so-called law of labor supply and demand. Decreased unit costs of labor output must be attained even at these higher wage rates through further enlarged scale production, improved management and the introduction of systems of wage payment which make a part thereof depend upon efficiency.

Summarized then, the four principal requirements which the electric utility industry must fulfill, if it is to maintain and improve its status, are (a) stabilization of rate of return through automatic regulation of rates, to the end that additional capital may be procured at the minimum cost, (b) improvement in utilization of existing plant facilities, (c) maintenance of present monthly wage rates of employes and the attainment of lower unit costs by more skillful management, and (d) framing of methods of compensation by which employes attain higher earnings in accordance with their efficiency, in which individual output is an important factor.

Water Powers

F. Darlington
Consulting Engineer,
New York City

IT DID not require a war to show the necessity for increased hydroelectric development, if we as a nation are to avail ourselves of our resources. Our failure in this work does not lie with the water powers, the power companies or the engineers. Water power development is at a standstill through the failure of our governmental and financial agencies to comprehend the true situation and to apply the obvious remedies. Until our laws governing power companies are revised and wisely administered, and co-operation secured between financiers, water power development will remain throttled, our industries will be taxed for lack of reliable and cheap power, our coal will be wasted and our railroad transportation burdened in an extravagant and foolish manner.

Unless our state or federal government goes into the power business, (and there is at present no governmental organization which promises efficient management in power production) the development of water powers will necessarily rest with public service electric companies, and the present laws and their application effectively bar satisfactory progress in this line. It is not necessary to discuss the recent failure of Congress to enact laws to permit hydroelectric developments on navigable streams and on federal lands. The repeated failure to pass this legislation is a grave charge against the efficiency of our national administration. But aside from legal restrictions that retard water power developments on navigable streams or federal lands, there are conditions which arise from ignorance, prejudice, selfish motives, or from unworthy political acts that curtail water power development with equal effectiveness and at a heavy cost to our national prosperity.

For example, no law which aims to prevent combinations of capital and centralization of industries should even be applied to combinations between public utility power companies, because the best interests of society require that these companies shall be monopolies. There are numerous sections of the country, each of which embraces several states or parts of several states, which are natural power districts, and where a single interconnected electric system joining up the industrial sections can furnish cheaper and more reliable power than can several independently owned and operated power companies. Our laws, both national and state, should encourage the setting up of such centralized power monopolies, with capital issues and rates regulated by government authority at a level to insure a reasonable income on their invested capital.

It is essential for the success of hydroelectric developments that there should be a national and state policy to secure both the principal and interest of capi-

tal invested in the public service electric business. Charges to capital constitute a much higher proportion of the cost of water power than is the case with power produced by steam turbines or any other method. If the people of this nation are to be supplied with cheap and reliable power, they must safeguard the earnings of electric power companies, so that the securities of these companies will be gilt-edged and freely purchased and will be sought by investors, even where the interest return is modest. This can be accomplished by public service commissions having authority over issues of securities and electric power rates.

The policy of the public service commissions of many states has been short-sighted and foolish, to judge by the results. These commissions seem to have had no better comprehension of their duties than to regulate the rates of public service companies to a starvation point and to prevent so-called monopoly combinations in the power business. This condition delays water development, not only by making the money for this work far more costly than it should be, but also by placing electric power undertakings in the class of hazardous investments, whereas there is no branch of industry that should be more certain of its return and more secure in its investments than water power undertakings.

Two examples may be given from among the great number which are indicative of the workings of governmental regulation of the electric business:—

A few months ago, two electric companies each having an interconnected transmission system, supplied by hydroelectric and steam generating plants, appeared before the state commission having jurisdiction over their capital issues, with an application for consolidation. They represented correctly that by combining the two companies and operating them as one system, they could better utilize the water powers of both companies and could eliminate much of their transmission expense and secure other valuable economies. The saving in coal alone by combining these two properties was estimated at an average amount of $200 000 annually. But notwithstanding the fact that this condition had been prevailing for some years, that the cost for this wasted coal had necessarily been paid by the power users of the community, and that these same users were being deprived of the more reliable service that could be rendered by the two companies combined, the state commission has permitted this condition to exist and has not yet found a way to realize the obvious advantage that would result from combining the two properties.

Again in a southern state there are three major central station electric-power systems, each having water-power and steam-power generating stations. This state has no coal mines but is blessed with extraordinarily valuable water power resources, for the best utilization of which the transmission lines of the present power companies should be effectively interconnected, and the operation of their generating plants placed under a single control. Such an interconnected system built with money carrying a modest rate of interest could produce power far more cheaply than can be done under the present conditions, where the three systems are inadequately connected, and each company operates with an eye essentially to its own requirements and resources. It is estimated that with adequate interconnection and with centralized direction of operations, there would be an average saving in coal of $260 000 annually, as compared with independent operation, and the service would be much more reliable.

In spite of this fact, one of the three power companies is considering the construction of a million-dollar steam plant for the purpose of augmenting its power supply, although the cost of power from this plant, if built, must for all time be far greater than the cost of power derived from available water power sources, and supplied through an interconnected power system. Such an expenditure for steam plant construction in a state without coal, but with abundant and superior water power resources, would result in either unnecessarily high rates to the consumers of power, or less to the investors in the power plant.

To stimulate hydroelectric development to the fullest profitable extent, it is, however, not enough to permit combinations to form regulated monopolies for power service and to protect the investors, but some incentive should also be offered for developments that will improve and cheapen power to consumers. As industries grow and power systems develop, possibilities arise for new developments and combinations of systems to reduce the cost of power production below that previously attained, and unless some incentive is offered in the way of a share in the savings by new and enlarged undertakings to realize the new possibilities, there will be a wholly natural disposition on the part of public service companies to continue along making the established profit permitted by the rates allowed them under governmental regulation. To overcome this inertia and to induce capital to engage in undertakings for the betterment of electric power supply, a broad-minded and liberal policy should be followed in the treatment of electric companies whereby they will share in the savings of new undertakings, and will be secured against capital loss on investments which may have been wisely made under past conditions, but which will be supplanted when new and more comprehensive plans are worked out to replace equipment that may be rendered obsolete by new developments. Recurring obsolescence of electric installations has been an unavoidable condition necessary in the industry, because both the engineering features and their commercial application have advanced rapidly during recent years. The disposition of governmental authorities to call for appraisals of electric properties and establish rates on appraised valuations without due regard to values that have disappeared through obsolescence, and that have not been replaced by suitable depreciation reserve, has done much to bring electric investments into disrepute

and raise the cost of money to the electric power industry.

It appears from a full review of the water power situation and consideration of the conditions described, that the field for hydroelectric production and the conservation of the nation's resources is more promising than ever before. The time is ripe for further consolidation and centralization to make cheaper and more reliable power, but progress in this development is hampered by unwise laws, and by unfavorable financial conditions brought about largely by short-sighted legislation and unwise regulation by governmental authority, for which our nation is paying a heavy penalty in the high cost of power service and waste of resources. This high cost and waste are bound to continue until the laws are modified, until more broad-minded direction and regulation of the electric industry are established by public service commissions, and until the securities of central electric companies, which should be as safe and sound as any investments, can be disposed of at low interest rates. All of this is in the hands of the federal and state governments to accomplish.

The Significance and the Opportunities of the Central Station Industry

R. F. Schuchardt
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IT REQUIRES little strain on the imagination to see that, in the not very distant future, practically every important industrial process and many domestic services will be performed by the aid of electricity. The arrival of that day will depend in a large measure on how well we individually play our part. The total result will be but the summation of our individual efforts. But is this universality of electricity "a consummation devoutly to be wished?" Those of us who are electricity salesmen will immediately and emphatically reply in the affirmative and will want to buttonhole the questioner for an hour or two to prove it. But those others who may be salesmen only of their talent or their labor, whose interest in selling electricity may be merely incidental, those others may not be given to figuring out what it is all for, and they may therefore hesitate in their answer.

It is a good plan occasionally to step into an airplane, as it were, and soar up into those freer regions from which the view of our camping ground down below, where our daily problems often press on us so closely that we fail to get their true perspective, loses all detail, and where hillsides (of boiler efficiency, of turbine design, or of generator protection, for instance) blend into valleys (of transmission line relays or of apparatus failures, etc.) and none seems all-important; but the big elements, the forests (of electrical industry, the handmaid of man and an important item in the advancement of his social well being), the broad, silvery rivers (of interconnected systems and a unified frequency), and the clear, shining surface of the lakes (of economical natural-resource-utilization, with no more waste gases, no more transmission of fuel where transmission of electricity is better, no more waters running down their mad course unchained, where there is need for the power), these elements stand out strongly and we see them in their true relation to each other.

On returning from such an ethereal trip our daily problems will take on a new meaning. We will have received a bigger vision of the significance of our tasks, and the results of our efforts will seem less ephemeral.

Why should not every one who finds himself, either by design or from accidental opportunity, in the central station game, be well contented to be a player in it? Any movement—and the establishment of an industry surely is a movement in the broadest sense—that benefits man gives satisfaction to the participants. Empire builders were not always altruists, but in so far as they opened up to many others opportunities to obtain and to realize on nature's resources they were benefactors of man. All credit to the early railroad builders whose daring and whose foresight made the present development of our country possible. All credit, likewise, to those whose vision and faith has speeded the centralizing of power production so that, because of cheap power, vast industrial centers have grown and have produced national wealth in great abundance. And with it this centralized production has, by its cleanliness, added greatly to the health and comfort of the people. Is this not enough to arouse enthusiasm?

"But," says Mr. Killjoy from his gloomy corner, "that was in days past. Centralized power production is here and all we do now is just naturally grow." Let us see if the remainder is barren soil. There was a day within the memory of men still living and active when a trip from New York to Chicago necessitated traveling over six different roads in series. Each road was a centralized system as far as its own locality was concerned. Today, any one of a number of trunk lines will make this run in a continuous trip. In like manner will present power transmission systems be joined up and this has in fact already occurred in many instances. No need now, after the past year's experience, to argue for ultimate interconnection. The *Electrical World* recently summed up the situation in these words:— "Progress and initiative must be the guiding principles of our public utilities. Economies learned during the war must be held and even bettered. The industry must go forward * * * and interconnection is a forward step." Ultimately the country will have a net work of transmission lines, carriers of energy, as it now has a network of railroads, carriers of material things. And this network will link up every economical source of power, be it a waterfall, a steam station, or a waste gas utilizer, with the habitations and the industries of man. Electricity will bring cheap power and comfort to every man's door.

What, then, can we do to speed this day? Principally we can plan all our present extensions so that, when the time is ripe in our locality, interconnection can be carried out most economically. This will best conserve our present investments and make the ultimate economies easier of realization. Had many of the earlier railroads been of standard gage and many others non-standard, the cost of interconnection would have been great, would have delayed the accomplishment and, finally, would have imposed an additional financial burden which would naturally have been borne by the railroad-using public. Somewhat the same situation will exist where transmission lines of different frequencies are to be interconnected. Differences in voltage are not serious since transmission line transformers are quite common and at times even present an advantage. The principal aim, then, should be to reach a common frequency, and since 60 cycles seems now to be generally accepted, special efforts should be made to develop satisfactory apparatus of all kinds for this frequency. Plant extensions should, wherever practicable, be made for 60 cycle supply.

Any steps, individual or collective, taken to educate the members of the next Congress on the importance of stopping the disgraceful water power waste will bestow a lasting benefit on the country, if they are successful in getting the required legislation passed to permit its proper use. Water power plants will naturally be an important element in the interconnected scheme.

Transmission networks spanning large portions of the country will no doubt be a big help in bringing about more extensive steam railroad electrification. The "battle of the systems", as it has been called, is subsiding and is giving way to a realization that the particular system to be used is not the most important part of the problem. This was encouragingly set forth at the March meeting of the A. I. E. E. in Boston. The vast coal conservation which would result from supplying to the railroads energy from centralized steam plants and from water powers makes this an attractive field for the expenditure of the best talent. Incidently it may be worth while to point out that at least two of the "systems" can readily be operated from the 600 volt local traction mains found in practically every city of any size. The rolling stock of these systems could thus receive energy within the cities from existing substations, with added capacity here and there as may be required, while outside of the cities, over the long stretches, the same rolling equipment could be used on higher voltage direct current (perhaps multiples of 600 or of 750 volts) or on higher voltage single-phase alternating current. The significance of this, both in increased use of present investment and in a high utilization factor for new investment, will be readily appreciated. Ultimately, the direct result will be cheaper power to the locality as well as to the railroad. It is not claimed that the above is the solution of the electrification problem, but because of the attractive possibilities, it is suggested for consideration. There is the further possibility, in the case of a direct-current system, of supply through simple automatic substations containing iron tank mercury rectifiers, should the development of these be carried to successful completion, as is hoped.

The central station man and the manufacturer could with profit try to inspire the engineers and the managers of power-using industries with a vision of the future so that they too will follow a trend of development in their special work which will readily fit into the ultimate power scheme. Particularly should this be done in the industries having waste heat or waste fuel as an incident in their processes. The steel industry, now having principally 25 cycle equipment, could more readily turn its heat waste to gold if it could cheaply tie in with 60 cycle power systems in the locality of its plants, (and possibly the very large, slow-speed rolling mill motors would do better on 15 cycles anyway, fed through a 4 to 1 ratio frequency changer on the 60 cycle supply). No investment ought to be allowed to be made for equipment that may and should some day be linked up with power systems unless such equipment is of the right kind for such linking up. This last merely means that the central station men ought to get closer together with the other fellow. Get his viewpoint and let him get yours and co-operate for the common good. The steps now being considered by the national engineering societies for a better co-ordination of their work and interests are a move in this direction.

Central station men should also get closer together among themselves and for this I know of nothing better, nor half as good, as the National Electric Light Association. This Association is organized to help give vision—a big, broad, fine vision of the industry's splendid opportunities. Use it. Use its committees. Serve. Reply to the questionnaires when they come to you. Of few societies can it be said more truthfully that "you reap as you have sown" or "give and it comes back to you." The men in the industry are a splendid lot and by closer contact with them you will catch their enthusiasm and their cheerful outlook on life, characteristics common to men who do.

The above are but a few suggestions. There is one final point that should be emphasized. Our army, that valiant body of men who saved the world, is a clean army. It typifies America. Let the Association members be sure that they maintain for their industry that same high record. Instances there were in the past, as in other industries, that utility managers are not proud of, and they must be lived down, but these were magnified in the public mind so that the stain seemed greater and more lasting than it was. Even yet there is a type of politician who, thinking to shine in Sir Galahad's armor, points to these instances in order to win credulity for his championship of the people's cause against an assumed wrong. It is your opportunity by example to prove to the world that the business is clean; it is yours to keep it, like Cæsar's wife, above suspicion. Your active interest in clean

and enlightened government, your participation in things that make for a better city and a better country will help materially. Hold up your hands proudly and insist on the world's understanding that a public service company is an organization conducted by trained individuals whose efforts are directed toward utilizing capital to produce for a community, as cheaply as possible, a commodity and a service the use of which improves living and working conditions of that community and in so doing earns for these individuals a return for their labor, and for the capital employed a return for its use.

The Primaries of Today the Secondaries of Tomorrow

W. S. Murray
Consulting Engineer,
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When you are hunting grizzlies in the Rockies, leave your Flobert rifle at home. Who of us, associated with electricity, has not smiled when the man who runs, say a laundry, has remarked as his imagination has tried to fathom the intricacies of an arc light, "Is it not wonderful, and to think electricity is still in its infancy." The smile that comes is a resultant of two components: one the knowledge of how little the laundryman realizes what electricity has accomplished, the other your realization that he is right. But what have grizzlies and laundrymen to do with our subject?

In a recent address at Boston, the following slogan was offered: "We have spent billions for destruction for preservation, now let us spend billions for construction for conservation". Today the woods are full of big game. We therefore want big weapons in our hands. Electricity, in our knowledge of the various forms of its manifestation and the wonders it can accomplish, is no infant. Notwithstanding the billions of kilowatt-hours that are produced in this country in a year, it is an infant as far as the possibility of its future application is concerned. The laundryman was not qualified to speak. Yet he was right.

We have become the wealthiest of all nations. The imperishable principles of democracy have won in the world's battle for supremacy. We have not unduly battled for this; it is the result of the natural forces incident to our national structure. The fairness and freedom offered in our national and state laws have brought the inevitable result of concentration of wealth among the few of this country, and yet after all how truly does this wealth belong to the nation! He who makes his fortune here keeps it here, and who can say that such wealth does not belong to the nation when the nation needs it? In the last year a man whose net income has been one million dollars, has placed $650 000 in the coffers of Uncle Sam's Treasury for the privilege of maintaining his free citizenship and that represented only one tax.

In the past, credit has come to our nation through the marvelous success attendant to individual effort. Today, one man's credit is worth what the whole nation's was one hundred years ago! In the future, would it not be a broader stand, and a fairer cry that we all stand behind the Nation, and let *It* do and take credit itself for the greater constructive works which must follow in this coming period of expansion which has already started.

We engineers know who Goethals is, and the splendid record of his work at Panama. His leadership and association in this work will never be forgotten by his fellow engineers and countrymen. But do you think, if one nation asked another, who built that canal, that the answer would be Goethals? No,—the United States. There are things in which the nation must interest itself and which in magnitude and return will transcend the Panama Canal. I will speak of only one of them, and that is Secretary Lane's plan which provides for the economic supply of electric power throughout the dense region of industrialism and railroad transportation existing between Washington and Boston. This is indeed a project worthy of the nation's steel. In the region above described, to visualize the waste that we are as a nation permitting is to liken it to an inverted cornucopia, with a golden stream running down the gutter of despair! Read what Dr. Arthur D. Little said in his article on "Developing the Estate" March *Atlantic Monthly*. Here is a quotation from it, "Could our people once visualize Niagara Falls as flowing coal instead of water and wasting its energy in a vast conflagration through the gorge, how long would they permit our miners to toil in tens of thousands underground and maintain even so grand a spectacle." This of course was water for coal, but remember it is coal for coal too, and it can be but half as much if only the power is correctly generated, transmitted and distributed.

We who have lived but two score years and plus, have been privileged to see the wonders of the electrical arts unfold and watch their equally wonderful application, and now can we who know what efficiency, load factor, diversity factor and breakdown service stand for, mark time and permit this inverted cornucopia to discharge the nation's wealth into this gutter of remorseless waste, when we know it can and how it can be stopped? Do we want another winter in New England like that of 1917-18? I say this feelingly for in the case of one plant in which I was interested and which was supplying millions of kilowatt-hours to munitions factories, there were about three hours of coal in sight to maintain operation and that the day was saved only by my personally going down to the freight yards, singling out six coal cars and riding them into the station grounds, and when I did this someone else had to suffer, but my conscience was clear, as a war necessity took precedence in my judgment over any other. And so it was all through New England. Why was this true? The answer is

simple. We are burning twice as much coal as we should, and transportation is miles behind the facilities required, if we are willing that this waste continue.

A central station supplying light and power today congratulates itself on its 40 percent load factor. What does a railroad offer? The load factor of the New York, New Haven & Hartford Railroad Company for combination of freight, passenger and switching service is or can be made to be 75 percent. What is the load factor of a steam locomotive? My guess might be as good as that of anyone else, and if it averages more than ten percent I would lose, for I would take the other side of the bet. However, I do not care greatly what the load factor of a steam locomotive may be since I have measured accurately the actual amount of coal used in the three classes of railroad service; passenger, freight and switching. The electric engine driven from power produced in a central station employing turbine units of only 4000 kilowatt capacity will replace steam engines ton for ton on drivers with respective coal economies in the ratios of 1 to 2; 1 to 2.5; and 1 to 3.

We know what electricity has done for the factory drive notwithstanding that the generator units locally installed must of necessity be of small capacity. Hence I leave it to your imagination what the saving to their coal piles would be when driven from a source of electric power supply, the minimum size units in which would be 40 000 kilowatts, with such a system supplemented, wherever possible, by power received from hydroelectric stations delivering their quota without the expenditure of a pound of coal.

All of the foregoing has to do with power. Let us touch for a moment on the byproduct economies incident to electricity's use. In the railroad again we see the ratio of 1:2, in the matter of maintenance of electric locomotives ton for ton on drivers as against steam engines. Here too, we see the electric locomotives, substituted for steam, lifting the limit of electric traction from the driving wheels and placing it on the draw-bars of the trains, or through the agency of multiple control any number of locomotive units being handled by one engine crew. This means of course the consolidation of trains and the immense economies made available through the reduction of train-miles.

Again, within reach of this highly economical power, will be the electric furnaces for ore reduction, the use of which is only beginning; such an application to be made as in the case of railroad switching service at the time of "off peak" power, thereby increasing the load factor of the system, and thus making available a maximum installed generator capacity. And midst all of these economic factors pertaining to regional electrification, stands out the invaluable adjunct of diversity factor and the guarantee of continuity of service by virtue of created breakdown service between power centers.

At first blush, this great regional plan or system might appear difficult of operation, and yet it is merely the assembly of detail already worked out. Electricity was first generated and distributed in a house; then in a city; the district followed, and does not the ascending curve of accommodation now point to a region? Has not each step made for economy and, with density of application satisfied within a regional territory, are we not ready to assemble the whole within this wonderful economic radius? England's superpower line is practically under way. If we are to maintain our supremacy in the world's markets while still maintaining the American standard of wage and living, are we not, as engineers, in duty bound to show the nation how its power can be increased, its unit cost reduced and transportation facilities made available for our coming expansion in industrialism?

Now let us not make a complex problem out of a very simple one. Let us constantly fix our minds on the result to be accomplished and the means to that end. Let us not get size and difficulty mixed up. Sometimes the largest things are the easiest. There will of course be opposition. There always should be resistance, though the thing be good itself. A sail-boat needs the resistance of the water, otherwise, it could not be steered. In this matter however, it is my belief that the resistance will be of a healthy order. It will come due to a lack of understanding which, when analyzed, will result in no real opposition. When you can say to the railroad man whose road derives most of its income from the number of tons of coal hauled that its rails will become a highway along which new industries will spring up by virtue of their proximity to efficient and economical power, will he not be more than willing to find cargo space automatically created in his cars to haul the new commodity, and does not such an answer carry with it a national inspiration, as does it not at once imply the opportunity of expansion of the nation's industrialism with the promise of a higher degree of economy for the unit production of power?

Again, some of the fairly large central station owners may say, What is to become of our plants? The answer is simple: This is the day of obsolescence. Depreciation bows its head to it. Its legs are not long enough to keep up the pace. Progress is the mentor. Look at the great horizontal-vertical engines of the Interborough Rapid Transit Company; the volume of whose low pressure cylinders alone, I venture to say, were large enough in which to place the revolving parts of the steam turbines of five times their capacity which replaced them. Why are these engines in the scrap heap? Had they worn out? By no means. Obsolescence. Thus the highest economy stations today on our Atlantic seaboard will be lowest of efficiency as compared with those contemplated for service in Secretary Lane's plan for conservation by the use of the super-power plan of generation, transmission and distribution.

This great regional plant as suggested by the Sec-

retary may be likened to a university; and plants at present constructed will have to pass entrance examinations in efficiency to matriculate in that university and those whose efficiencies are such as to disqualify them will find themselves obsolete and their owners ready to take power from the super-power line. Secretary Lane's plan does not contemplate taking any individual or corporation's business away. On the contrary, he is offering the opportunity of a bigger and more efficient business to all.

We are mining 580 000 000 tons of bituminous coal per annum—a jump from 100 000 000 a year during a period of 20 years! Our railroad facilities are far behind transportation requirements. Why? Because 33 percent of our cargo space is filled with this essential but unclean commodity. How long do you wait for the raw material which is finally to leave your factory as a finished product? Usually until you are out of breath. Why do you wait? Coal. Coal. Coal. It clogs the yards. It clogs the sidings, and it clogs the main lines. We refine oil and ore at their sources—why not power?

Though there are a hundred arguments, which for lack of space and time must remain unwritten, let us think seriously of the possibility of a great common carrier of electricity. If we cannot refine all the power at its source, then let us refine the remainder at great stations located by the sea, using tugs and barges instead of locomotives and cars to haul the raw material of these power factories, placing the finished product up overhead, thus releasing the railroads of part of their burden. I look for the day when such a great electrical common carrier between Boston and Washington will be an accomplished fact. Such a carrier will transmit to the primary wires of present day companies and new companies to come electrical energy produced with half the coal consumption per kilowatt-hour which is required today. And so, as the caption of this article reads, will the primaries of today become the secondaries of tomorrow.

Let us make this a national matter and also, as engineers, let us contribute every ounce of backing, moral, physical and intellectual to the Secretary's thought. Whether such a great regional plant or system is owned, financed or controlled by federal or by private interests, these matters will get due consideration by the proper parties at the proper time. Secretary Lane's plan is preliminary to all things. He wishes to prove beyond peradventure of doubt that the waste is there, and what it amounts to. His words to the Congress are concise and to the point in the bill which he has framed, reading:—

"[illegible] and report on the power supply for the Boston-Washington industrial region to determine the economy of fuel, labor and materials, resulting from the use of a comprehensive system for the generation, transmission and distribution of electricity to transportation lines and in[illegible]

The resolution of the American Institute of Electrical Engineers at their recent convention in Boston endorsing Secretary Lane's plan will doubtless be a matter of gratification to him, since it comes from the greatest organ of American electrical jurisprudence.

We will do well to keep our engineering minds on two things; the result, and the ways and means to accomplish it. If it is done, it will help the nation to earn a new title. We are known as a nation of wealth. We who have had so much have known that waste has been its complement. Let us make ourselves known as a nation of economists. The plan as offered by Secretary Lane offers no place for selfish, individual profits. It smacks of altruistic loyalty to the conservation of our national resources and commends itself to those who think and act along such lines.

Central Station Profit Sharing

Wm. C. L. Eglin
Vice-President,
The Philadelphia Electric Company

One of the important matters which is being given thoughtful consideration at this time is that of profit-sharing with employes. During the war, the labor problem was one of the most difficult questions presented to the industries of the country and particularly to those industries which were essential to the prosecution of the war. The selective draft program necessarily demanded that every man of the requisite physical qualities should be first assigned to the fighting forces, and that only such men as were very decidedly of greater value in these essential industries should be exempt. The withdrawing of this large number of producers and the additional demands for increased production of war materials caused a shortage of labor; the natural consequence of which was a very rapid increase in the wages paid to labor. Most of this increase was considered justified because of the general advance in the price of all materials and foodstuffs due to the war.

Since the close of the war, a great deal of time and attention has been spent in a study of this subject of labor and wages. This study has been carried on both by committees representing different departments of the Government and by State committees and others. Many of the educational institutions are also making special studies of this subject, in the endeavor to increase the output of the individual, so as to justify and maintain the existing higher rate of pay. The electrical utility companies are, for many reasons, vitally interested in the studying of, and should be leaders in, the promoting of equitable standards of labor. Fortunately, the electrical industry is young enough not to be troubled with any serious prejudices.

The men in this industry, through the training received in an industry which is largely pioneer in its work, have been developed along broad lines. The importance of their work and their responsibilities have increased from year to year. Recognition should be given to the employe for this added responsibility. The rapid increase in the size of the generating units and in

the amount of energy which has to be transmitted; the added complications of the switchgear and measuring instruments; the growing necessity of effecting minor economies in order to increase the efficiency and reduce the maintenance costs of generating and distribution equipment, and the increasing importance of reliability of service must be met by improvements in the type of the personnel—requiring additional, specialized training to fit the man for the position.

It seems reasonable, also, that in the future, recognition should be given for the results which any group of employes in the company organization has helped to bring about; that is, some profit-sharing method should be devised which would be applicable to each group of individuals in the industry, so that the economies effected through the teamwork of any group should be, in part, available in the form of bonuses or dividends to that group. It is not unreasonable to expect that the electrical industry can lead in this work and should be able to provide a plan that will be applicable to each department.

Value of Automatic Railway Substations to Central Stations

C. F. Lloyd
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THE CENTRAL station carried, and carried well, a generous share of burdens imposed upon it by economic and physical conditions incident to the war. Aside from the financial strain, the equipment in many cases was taxed beyond capacity by the old customers doubling and tripling their demand, almost over night, to say nothing of the many new customers that were added. However, one cannot escape the conclusion that the central station performed admirably, and has benefited by, the circumstance of the war, even though the temporary burdens have been heavy and have not disappeared with the cessation of hostilities.

Due to the shortage of power in some of the eastern manufacturing centers during the winter of 1917-18, the Federal Government made power surveys in several sections, the majority of which, showed enormous waste of fuel. Results of calculations showing the savings that would result by operating one efficient central station to supply all the power manufactured by the small inefficient plants with low load factors, were astounding. Again it was clear that the service, potentially, would be far superior with the large central plant. These conditions, circumstances, and facts have made an indelible impression on the Government, financial world, industry in general and the public in particular, which no doubt, would have been delayed many years in the ordinary course of events. Obviously, this inestimable opportunity must be followed up without delay if the central station is to reap its just benefits. To this end, what better problem presents itself than a universal combination of central station and railway loads?

Regardless of the present unfavorable financial condition of the electric railway systems, the country must have transportation in increasing amount and there is no adequate substitute for electric traction. There is going to be a solution of the financial problems of the traction companies and it seems safe to assume that one item, that will help the situation, will be the more general use of purchased power, preferably direct current, thus leaving the railways free to devote their entire time to their real problem—transportation.

From this view point the possibilities of the automatic substation are of vital interest to all central station engineers, since it presents enormous possibilities in the solution of the problem of selling direct-current power to the electric railways at a figure that will realize a fair margin of profit and one which the railways cannot afford to neglect. Automatic substation switching has reached a state of development where it must be taken into serious consideration if we are going to do our share in the joint conservation of capital and the country's resources, and to use labor more effectively.

Power House Economics

E. H. Sniffin, Manager,
Power Department,
Westinghouse Electric & Mfg. Company

THIS NUMBER contains a very interesting article by Mr. W. S. Finlay Jr. describing in considerable detail various interesting features of the 60 000 kilowatt three-element turbogenerator unit now in operation at the Seventy-Fourth Street Power Station of the Interborough Rapid Transit Company in New York. The student of power house economics will find no subject within that sphere of engineering to be of more engrossing interest than the rapid improvements in standards that have been taking place in steam turbine practice. Indeed there is still such a diversity of practice, so many arrangements of turbine unit layout and such a difference in views on the subject, that the engineer should neglect no opportunity to become well posted on the details of design, operative features, relation of turbine size to system capacity, in fact all questions bearing upon this phase of central station practice. The Interborough unit, the largest in the world and the only three-element outfit in service, marks an interesting chapter in the recent progress of the steam turbine art, and is well worth a careful study.

Sixty Thousand Kw Turbine-Generator Installation

At the 74th Street Station of the Interborough Rapid Transit Company

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The size and unusual design of the 60 000 kw turbine recently installed at the 74th Street power station of the Interborough Rapid Transit Company in New York City, warrants a brief description of the installation, and especially of the unusual engineering features in connection with the foundations, piping, general arrangement, etc. During the period between 1913 and 1915, four of the original equipment of nine double, horizontal-vertical, cross-compound engines of the Manhattan type, with their 5000 kw Westinghouse generators, were scrapped to permit the installation of three cross-compound 30 000 kw Westinghouse turbine units To a certain extent, the general arrangement of these units in the plant dictated the relative location of the new 60 000 kw unit, making it necessary to bridge the station discharge tunnels with a heavy girder construction, upon which was superimposed the steel and concrete foundations. The only difference of any note was in the provision for direct support of the condenser shells by this foundation steel-work.

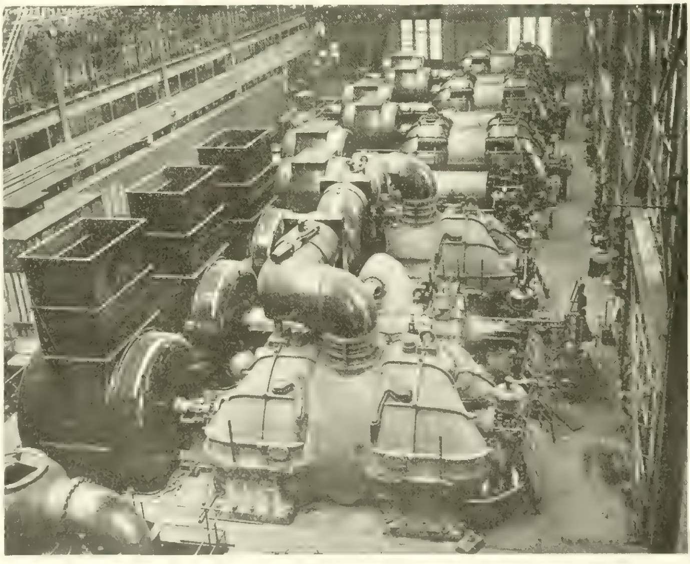


Fig. 1—General View of 60 000 kw Cross Compound Westinghouse Steam Turbine in the 74th Street Station of the Interborough Rapid Transit Company

The transmission of vibration was guarded against by the careful structural isolation of each turbine element's foundation, the surrounding floor merely resting upon the foundation without solid bolting or riveting. Certain of the column footings and grillages had to be carried well below the basement floor level being, however, well set in rock to offset any possible weakening due to circulating water pipe trenches.

Concentration of auxiliary equipment and piping was necessarily involved and, particular precautions were taken, throughout the development of the plans to provide a clear operating floor and ready access to machinery, valves, etc. It was also considered desirable to have the auxiliaries within reach of the cranes to facilitate dismantling and overhauling during off-peak hours. Another fairly important feature upon which emphasis was placed, was absolute uniformity of similar auxiliary units, viz: avoiding right and left-hand arrangements, thereby reducing the necessary stock of spare parts.

The result of the studies in this connection was the scheme shown in Figs. 3 and 4. The circulating pumps, which are geared-turbine driven, were designed with intake and discharge openings in the lower half of the shell, permitting the rapid removal of the upper half for inspection or repairs with a minimum disturbance of piping attachments. These pumps were located immediately above the intake tunnel, the suctions utilizing existing openings. The general design of the discharge piping to the condensers was carried out with a particular care to securing an even distribution of circulating water between the two shells. Rubber expansion joints similar in type to those utilized in connection with the 30 000 kw installation were installed in the lines to prevent transmission of expansion strains, etc.

The discharge piping was placed in trenches and, after careful study as to possible expansion and contraction strains, was incased in concrete to a large extent, by filling in the trenches. Before doing this,

however, the pipe was wrapped in heavy paper, leaving a smooth parting between itself and the concrete, the joints being left exposed in pockets which were afterwards filled in with coal-tar, and the whole floored-over with cement. The idea in using tar was to provide a plastic medium which would permit small movement due to expansion, at the same time serving to seal the joints.

The vacuum pumps, three in number, of the Le Blanc hydro-air type, take their water from the circulating piping, discharging to the circulating tunnel. They were piped up to the condensers so as to permit of a variety of combinations and considerable flexibility of operation. The hot well pumps were located in a depression below the condenser shells, being easily reached for operation and maintenance purposes. The

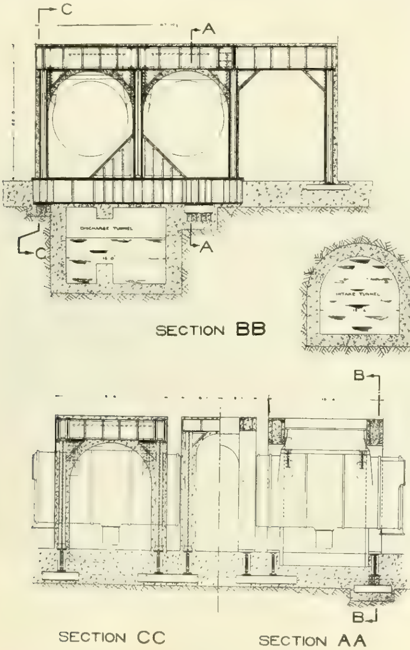


FIG. 2—TURBINE FOUNDATION

air washer system was installed in fairly close proximity to the auxiliary equipment, at the same time with little or no cramping of space conditions.

The atmospheric relief system necessitated provision of relief valves connected to the condensers, and a single back pressure valve set for 66 lbs. pressure connected to the high-pressure element, all discharging through a common 48 inch riser to the roof of the plant. Atmospheric relief valves from the engines were utilized on the condenser relief system, there being two to each pair of condensers.

The main high-pressure steam piping consists of two 18 inch lines carried with wide and ample sweeps from the header in the boiler room each through a throttle valve to a single primary turbine inlet. Additional quick closing valves were installed for emergency service, this duplication generally contributing to the reliability of the unit. The idea of maintaining maximum reliability and flexibility was further carried out by applying the loop idea to the steam lines of the

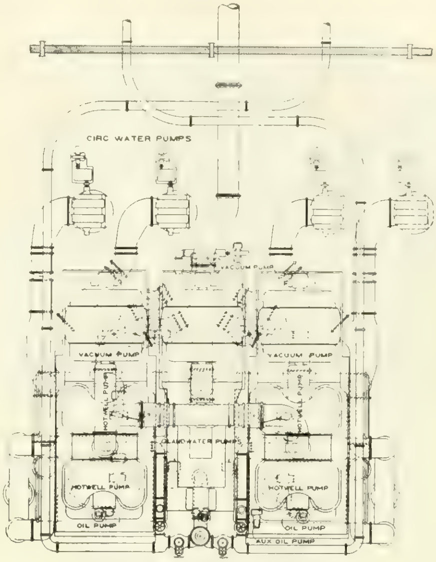


FIG. 3—PLAN OF TURBINE INSTALLATION
Showing circulating water, atmospheric exhaust and high-pressure steam lines.

auxiliaries, the whole scheme being, if possible, to obviate the possibility of any section of the system being shut down by reason of a break in the steam lines or because of valve trouble. Rapid operation of large valves is insured by the utilization of motor-operating attachments, but in spite of such provision, each valve, wherever possible, was placed in a position within reach for hand operation. A typical example is that of the valves upon the circulating water piping.

The oil system of the unit was also planned with the idea of maintaining maximum flexibility. Particu-

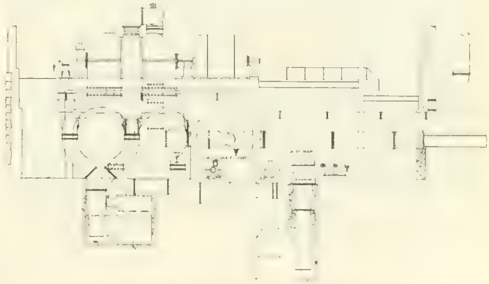


FIG. 4—SIDE VIEW OF TURBINE SETTING
Showing circulating water and atmospheric exhaust piping.

lar precautions were taken to have the oil coolers accessible to permit ready removal of coils.

One somewhat novel feature of the installation was the displacement of the ordinary copper expansion

joint by a specially designed rubber and steel joint. This joint, Figs. 10 and 11, should not be confused as to type with the smaller joints used upon circulating water piping, the smaller ones being designed upon a completely different mechanical basis. When the idea of securing maximum flexibility between the condensers

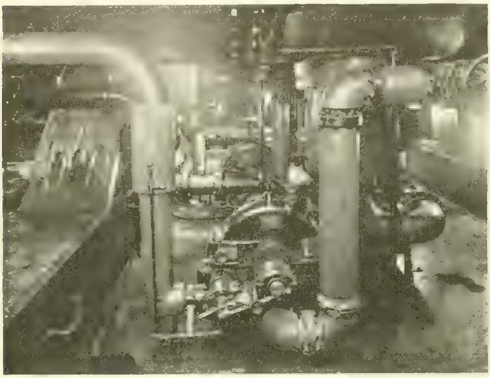


FIG. 5—VIEW OF HOT WELL PUMPS

and turbines was being given consideration, various schemes, such as the ordinary copper joint and the mercury seal joint were considered; but with full appreciation of the unreliability of the copper joint and its actual lack of flexibility, and the difficulty of securing a satisfactory mercury joint, it was finally decided to adopt a reinforced rubber joint.

Numerous tests were conducted to determine the suitability of materials and relative desirability of designs. For instance, it was found that, with the large pressure that would be exerted upon the joint when in service, it would be impossible to utilize any construction which involved running bolt holes through the rubber.

[illegible] PUMPS AND VALVES

The general scheme utilized in the construction of an ordinary automobile tire was then followed out by designing a bead with circular cross-section for use on the outer edge of the rubber, this being gripped between the joint flanges and sectional blocks, the general idea and details being shown in Fig. 11. Unusual mechanical strains had to be provided for by reason of the shape of the joint. These strains and the normal pressure strains were provided for by the introduction of a floating reinforcement ring located midway between the condenser and turbine openings. This floating ring is supported by an interior shield fastened to the lower flange which in turn is bolted to the condenser opening. Extending upward, and bolted to the reinforcing ring, is a second shield. These shields were designed to guard the rubber against erosive action of steam flow and at the same time serve as the inner walls of a water jacket, also a means of protecting as well as preserving the rubber. Gages outside of the joint indicate the level of the water and the jacket is maintained constantly full under normal operation. A particular feature, for which careful provision was made, is the possibility of withdrawing or installing the joint, without removing the turbine from its foundation, it being readily handled through the exhaust opening and from the inside.

Without going into a detailed discussion as to the relative merits of a joint of the type as described above,

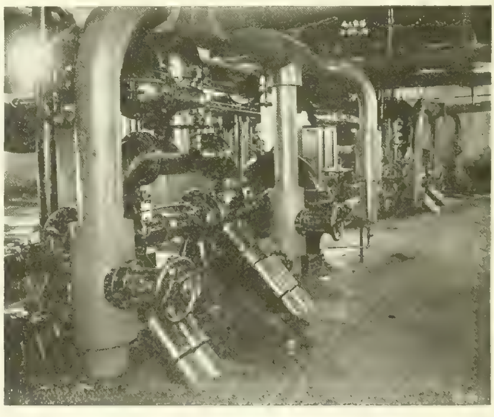


FIG. 7—VACUUM AIR PUMPS

it may be said that there is no reason why rubber, as a material, should not prove as satisfactory as copper or other metal, if proper factors of safety are provided in the design.

From an electrical point of view the unit's connections were adapted to the general scheme applying to the 30 000 kw compound units, detailed descriptions of which were given several years ago.* This adaptation involves the following:—

Each generator has a separate oil switch connecting it to a short generator bus. From this bus the current can be led to each of two main bus sections through oil switches or to the transfer bus through another oil switch. It is possible by this form of construction to operate each element separately or in any combination desired. In practice, however, the three generator

*See article in the JOURNAL by M. C. McNeil, June 1915, p. 271, and by Messrs. Stott and Finlay, July 1916, p. 335.

switches are closed and the whole unit brought up to speed as one, the synchronizing being done through one of the oil switches leading to the main bus sections or transfer bus. The proper disconnecting switches were placed in series with the oil switches, some of them being remotely controlled. Suitable current transformers and potential transformers with their proper instruments were installed so as to measure the output of each generator separately, there being in addition a large totalizing transformer by which the combined loads of the unit can be metered on one instrument.

Reactance coils of five percent value were inserted between the generator bus and the two sections of the main bus, and another of two percent value between the generator bus and the transfer bus. The percentage values are five percent and two percent of the star voltage when carrying one-half load. Each generator is protected by a relay system devised by the late Mr. H. G. Stott, which is a modification of the Merz-Price system. Should a burn-out occur in the windings of any generator, the unbalanced currents will operate a

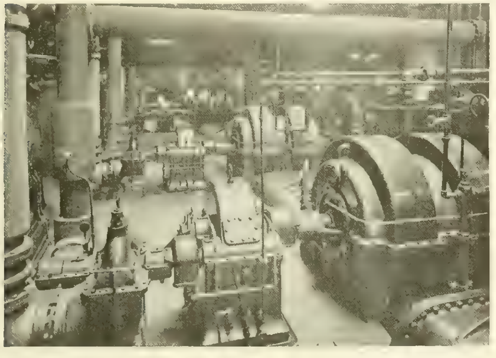


FIG. 8—GEAR TURBINE DRIVEN CIRCULATING WATER PUMPS

relay which in turn will open the oil switch, disconnecting the generator from the line.

To summarize and to restate the considerations controlling the design of the installation as a whole, constant thought was given to and provision made for supplying every device and taking every precaution to secure conditions conducive to satisfactory operation of the turbine and its auxiliary equipment and, although this might be said in connection with any large installation, it is the opinion of the engineers who have been active in carrying out the work, that at least some of the features described in the foregoing are somewhat exceptional in these respects.

The steam turbine itself is of interest not only because it is the largest prime mover in service in the world, but because of many interesting features in its construction, it being the first of the three-cylinder turbines to be put in operation. The machine has a maximum continuous capacity of 60 000 kw, and 70 000 kw for two hours. It occupies a floor space of 52 by 50 feet, and at maximum load requires 826 000 pounds of steam per hour.

The unit is designed on what is known as the cross-compound principle, and consists of one high-pressure turbine and two low-pressure turbines, each element being coupled direct to its generator, all three elements when in normal operation being tied together electrically. The steam path is such that all the steam passes through the high-pressure element, then divides equally and flows through the two low-pressure elements. This principle of design, by dividing the work done into separate cylinders, allows smaller individual elements which are inherently stronger than large cylinders; it makes possible an outfit considerably more flexible than a single large unit, and more reliable because the turbines are smaller and there is less temperature difference in any one cylinder; and commercially common materials with moderate blade speeds and stresses can be used.

Although this unit consists of three separate elements, the method of starting the elements from rest preparatory to synchronizing is essentially the same as

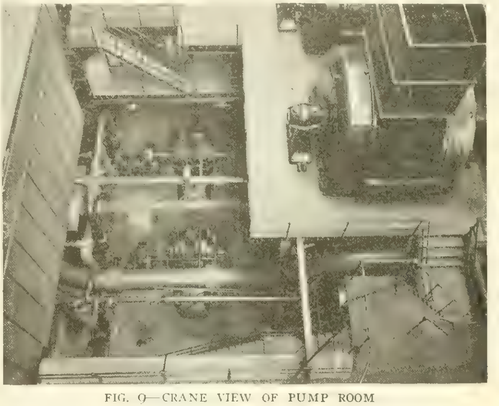


FIG. 9—CRANE VIEW OF PUMP ROOM

for single shaft units. First, the field current of all three generators is applied, then the throttle valve on the high-pressure element is partially opened. As soon as the high-pressure rotor starts revolving, it will, through the applied field current, start the rotors of the two low-pressure elements revolving. This causes all three elements to come up to speed together and in correct phase with each other, so that when synchronized with the system they can be connected to the main bus-bars by closing a single circuit breaker.

By the use of an ingenious governing arrangement, means have been provided that will permit uninterrupted operation of each individual element, should one or the other two elements be taken out of service by tripping the automatic stop from any cause not affecting all three elements. For example, if the high-pressure element be shut down, each low-pressure element will automatically receive high-pressure steam direct from the boilers through its own individual high-pressure steam system, whereas in normal operation the low-pressure elements do not receive any high-pressure steam direct. Vice-versa, if the two low-pres-

sure elements be shut down from any cause not affecting the high-pressure element, the high-pressure element will continue operating and automatically exhaust its steam into the atmosphere; but should only one low-

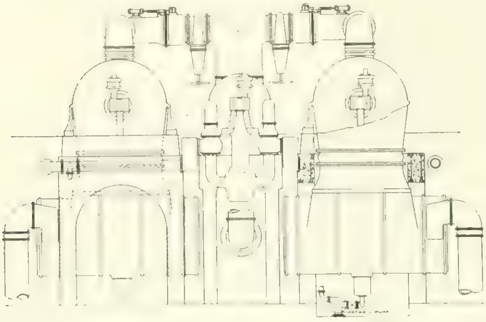


FIG. 10—FRONT ELEVATION OF TURBINE AND CONDENSERS
With right-hand side broken away to show expansion joint.

pressure element be removed from service, the high-pressure element will exhaust into the remaining low-pressure element. All this governing arrangement, as before stated, is entirely automatic. Such flexibility, needless to state, is not possible with turbines employing a single generator unless they be of as small capacity as one of the elements.

This unit is built entirely on the reaction principle, in contradistinction to most Westinghouse turbines of

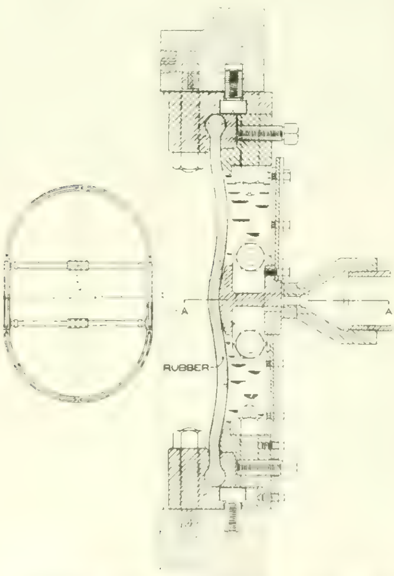


FIG. 11—DETAIL VIEW OF WATER-COOLED RUBBER EXPANSION JOINT BETWEEN TURBINE AND CONDENSER

moderate capacity where the high-pressure section consists of an impulse element. This change is due to the enormous volumes of steam which are to be handled, thus permitting of relatively long blades in the first rows of the high-pressure element with the result that the reaction rather than the impulse design becomes the more desirable.

The high and low-pressure turbines are proportioned so that with a total load of 60 000 kw the load will be equally divided between the three elements. In case of the failure of one of the low-pressure elements, it would be called upon to carry an abnormal load, since all the steam from the high-pressure element must pass through one low-pressure turbine. To provide against injury to the generator from this cause there is provided a back pressure valve on the exhaust of the high-pressure element which, when the pressure has reached a given amount, will permit steam to exhaust direct to the atmosphere. The pressure selected is that which corresponds to a load of 30 000 kw on the low-pressure turbine, which it is well able to sustain for half an hour; one-half hour being regarded as sufficient time in which to get other units on the system, when the load on the high-pressure and one low-pressure of the triple unit may be reduced to the limits of the continuous capacity of the low-pressure generator.

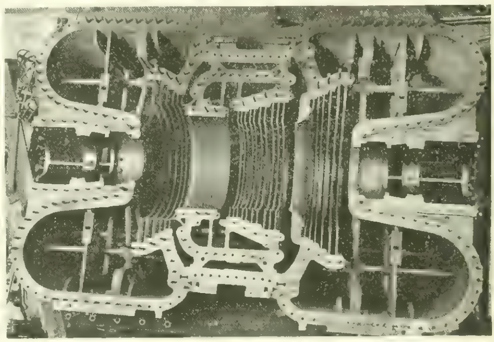


FIG. 12 LOWER HALF OF LOW-PRESSURE CYLINDER

As regards steam flow, the high-pressure element is of the single-flow construction, in which the steam enters at one end of the cylinder and flows in one direction to the other end of the cylinder, where it is discharged. The low-pressure elements are of the semi-double flow arrangement, where the steam enters near the center of the cylinder and all flows through a portion of the blading in the same direction. It then divides, and one half of the steam continues traveling in the same direction. The other half flows in the opposite direction through a suitable passage surrounding the single-flow stage, and then through the other low-pressure stage to the condenser.

The high-pressure element contains 50 rows of blades, the height of the first row being four inches and that of the last row nine inches. The journals are ten inches in diameter, which gives a very conservative journal velocity of 65.5 ft. per sec. The rotor is equipped with a Kingsbury thrust bearing, the function of which is to prevent any axial movement of the rotor. Due to the high temperature of the steam entering the

turbine, the cylinder of the high-pressure element is made of cast steel.

In this three-cylinder turbine, inasmuch as the steam passes the low-pressure elements in parallel, the heat drop through the low-pressure turbine is twice

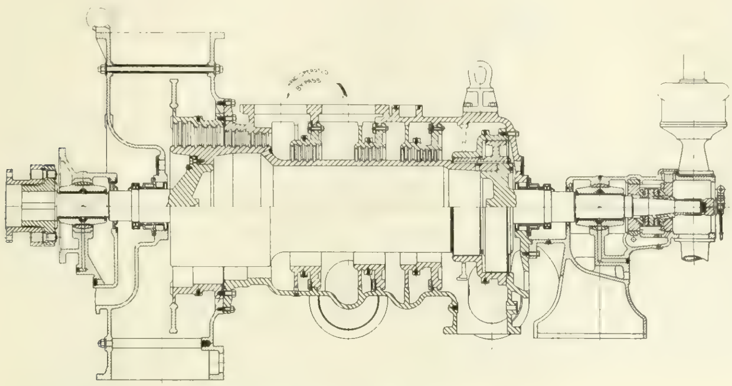


FIG. 13—SECTION THROUGH HIGH-PRESSURE TURBINE

that which would be obtained were there but one low-pressure turbine, because of the three generators being of equal capacity. This has the advantage that the piping between the high and low sections are very much smaller, being in this instance but three feet, five inches in diameter. There is a further advantage that a low-pressure turbine may operate alone with high-pressure steam with relatively good economy, the low-pressure turbine operating alone having a steam consumption of 14.25 lbs. per kw-hr., the high-pressure and one low-pressure turbine having a steam consumption of 12 lbs. per kw-hr.; these figures being comparable with 10.7 lbs. per kw-hr. at the best point of steam consumption for the complete unit.

Each low-pressure element contains 44 rows of blades. The height of the first row is six inches, and that of the last row is 15 inches. In this element the turbine rotor journal is 12 inches in diameter, being larger than that on the high-pressure element because the rotor is heavier. With this journal diameter there is still a conservative journal velocity of 78.5 ft. per sec. The rotor, as in the case of the high pressure element, is also equipped with a Kingsbury thrust bearing. Due to the low-pressure turbines being designed to operate in an emergency with high-pressure steam at its initial pressure and superheat which, when expanding into the pressures obtaining in the low pressure turbine, has its superheat much increased, being approximately 230 degrees F., or a total temperature of 509 degrees, the central portion of the turbine is all made of steel. There are in all four surface condensers installed, two being connected to each one of the low pressure elements. The total area of cooling surface is 100 000 square feet.

The unit is designed to operate with steam of 205 lbs. per sq. in. gage pressure, superheated 150 grees F.; and to exhaust at temperature of 540 degrees F., and to exhaust at a vacuum of 29 in. of mercury (referred to a barometer of 30 in.). At the load of 40 000 kw, which is the point of best economy of this unit, the high-pressure element will receive its steam at a pressure of 211 lbs. per sq. in. absolute and a temperature of 538 degrees F. and exhaust it into the low-pressure elements at a pressure of 29.7 lbs. per sq. in. absolute and temperature of 250 degrees F. in which elements it is further expanded down to the pressure in the condenser, viz., one inch mercury absolute and a temperature of 79 degrees F.

Each turbine runs at a speed of 1500 r.p.m. and is connected to a generator of 20 000 kw continuous capacity and 23 500 kw capacity for two hours, which is delivered at 11 000 volts, three phase, 25 cycles. As previously stated, each element has its individual bus-bars with separate feeders. Installed in the connections between these bus-bars are reactance coils which will permit of only a limited amount of current flow-

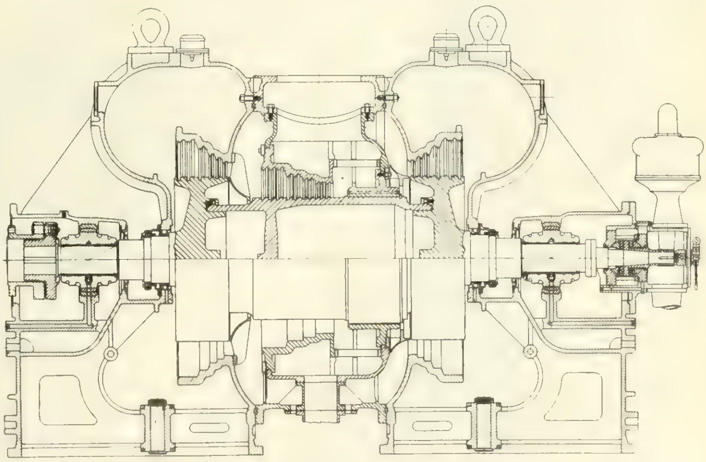


FIG. 14—SECTION THROUGH LOW-PRESSURE TURBINE

ing between the generators. Any tendency for an abnormal flow in current through the reactances causes a circuit breaker to open the circuit. This is done for the purpose of insuring the continuous operation of the remaining elements should a short-circuit develop in the feeder system of any one of the three elements.

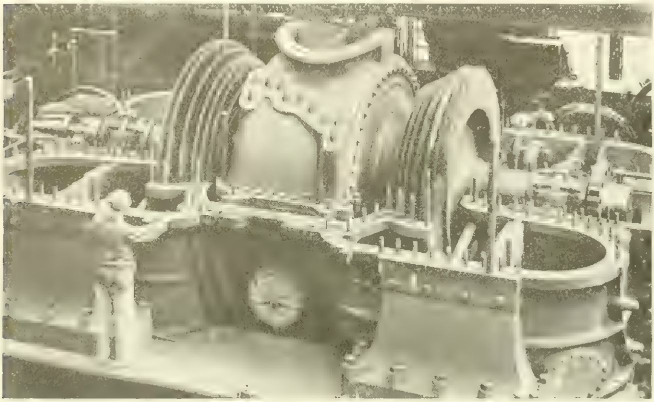


FIG. 15—LOW-PRESSURE TURBINE
With main cover removed and internal cylinder in place

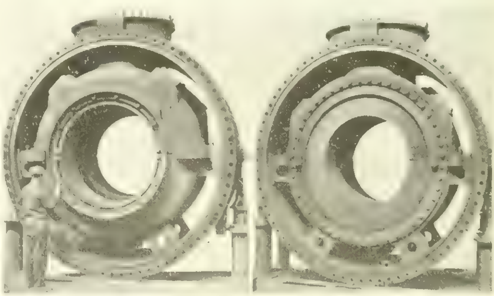
Since the governing mechanism must control three units—not only when operating together, but when operating separately,—it involves several features novel in steam turbine practice. Each unit is provided with an overspeed stop governor which will immediately shut off the steam from that unit if the speed rises above a predetermined amount. Each unit is also equipped with a speed regulating governor of which that on the high-pressure unit is of the customary form. The speed regulating governors on the low-pressure units are somewhat more complicated.

A butterfly valve, capable of automatic operation, is provided in each connection between the high and low-pressure units which will be automatically closed should the low-pressure turbine speed exceed the predetermined limit. This is tripped shut first by the speed-regulating governor should it go to the outer position, and in event of its failing, then by the automatic stop governor. The high-pressure turbine is provided with another exhaust having a back pressure valve so that when necessary the exhaust from the high-pressure turbine may pass to atmosphere, and the high-pressure turbine continue to carry its load.

Similarly, should the high-pressure element lose its load, its governor will cut off steam to the whole system. If the governor does not control the turbines and its speed reaches the predetermined limit, then the stop governor on the high-pressure will close the automatic throttle, similarly cutting off steam from the whole system. The whole system will then slow down until it reaches a predetermined speed lower than normal, when the governors on the low-pressure turbines will cause live steam to be admitted directly to them.

The high-pressure turbine governor is adjusted for close regulation, say three percent for its total range. It is necessary, of course, that the system operate from no load to full load, that is, be subjected to the speed variation in this three percent range, without the low-pressure governors performing any of their functions, admitting live steam to the low-pressure turbines on the one hand, or closing the connection between the high and low on the other. Hence, the travel of the low-pressure governors may be said to be divided into three zones; the outer position of the governor weights operating the butter-fly valves, admitting steam to the low-pressure element; the inner position of the weights controlling and regulating the admission of high-pressure steam to the low-pressure turbines. Between the outer and inner position is a portion of the governor travel which is called "neutral," and when the governor is within this portion of its travel it has no effect on any of the control apparatus.

It is, of course, desirable that if there be load variations within the limits of the capacity of the machine and resulting speed, the low-pressure governor should not go outside of its neutral limits and cause disturbances to the system by performing any of the functions that it should perform in the emergencies for which it is intended. It is, therefore, important that under normal operating conditions this low-pressure governor be maintained in its neutral position, at which time there may be the maximum variation from normal frequency either up or down, before live steam is admitted to the low-pressure on the one hand, or low-pressure steam cut off on the other. Hence eleven lamps are provided on the switchboard which give the operator an exact knowledge of the position of the low-pressure governor. Means are also provided by which he may change the tension of the governor spring from the switchboard in



(a) (b)
FIG. 16—INTERNAL CYLINDER OF LOW-PRESSURE TURBINE
a—Looking towards generator end.
b—Looking towards turbine end.

order to maintain this governor in its central position at all times while the unit is operating normally.

The total range of the low-pressure governors will be approximately 12 percent. Counting from the

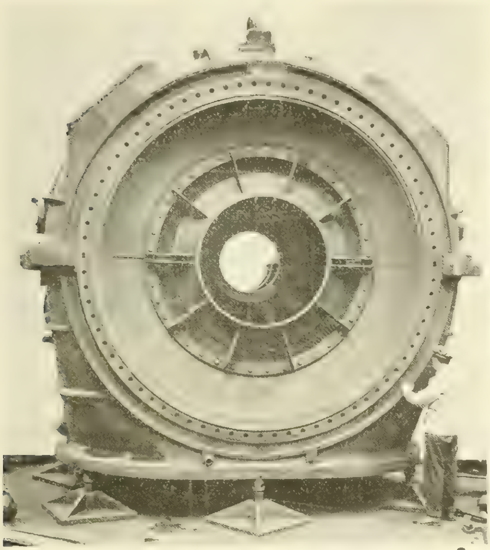


FIG. 17—LOW-PRESSURE SECTION OF LOW-PRESSURE CYLINDER

central position, if the turbine speed rises three percent, the governor will come into the position to close the low-pressure gate valves; before it rises four percent the low-pressure valve should have been tripped

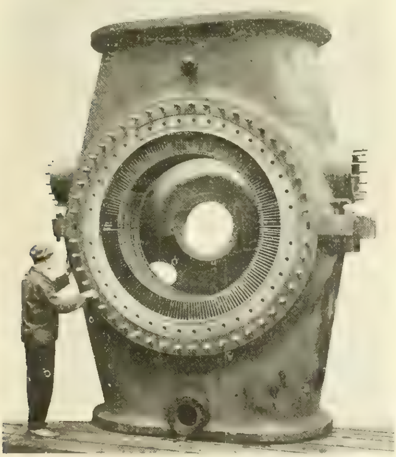


FIG. 18—LOW-PRESSURE CHAMBER OF HIGH-PRESSURE TURBINE

shut. The governor then has a little extra travel, corresponding to one percent change to take care of improper adjustment. Going downward from the central position, should the turbine speed decrease three percent, the valve admitting high-pressure steam to the low-pressure turbine will begin to open, and then with a further fall of three percent in speed, this valve will become fully open, and then again the governor has a little additional travel corresponding to one percent change in speed to take care of errors of adjustment. The three percent range between the high-pressure governor valve commencing to open and being fully open is necessary in order that it may regulate the tur-

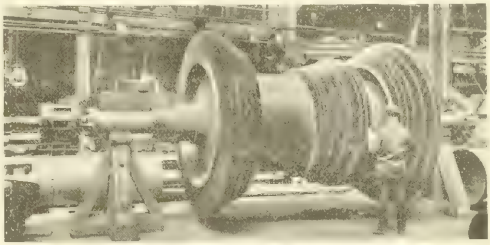


FIG. 19—LOW-PRESSURE TURBINE ROTOR

bine properly when operating with high-pressure steam direct.

When the governor is central the signal lamp CENTRAL will illuminate, and as the lever goes up the signal lamp UPPER NEUTRAL will first illuminate, which will remain alight until the signal lamp marked NEUTRAL will also illuminate. As the lever continues rising the UPPER NEUTRAL lamp will go out and the LOW-PRESSURE ABOUT TO CLOSE will illuminate. Further motion will also illuminate the signal lamp LOW-PRESSURE INLET,

FIG. 20—MAIN POWER CONTROLLED VALVE

and LOW-PRESSURE CLOSED. The operation in a downward direction is similar.

There is a butterfly valve in the low-pressure line which is controlled from the governor of the corresponding low-pressure turbine. Each valve is operated

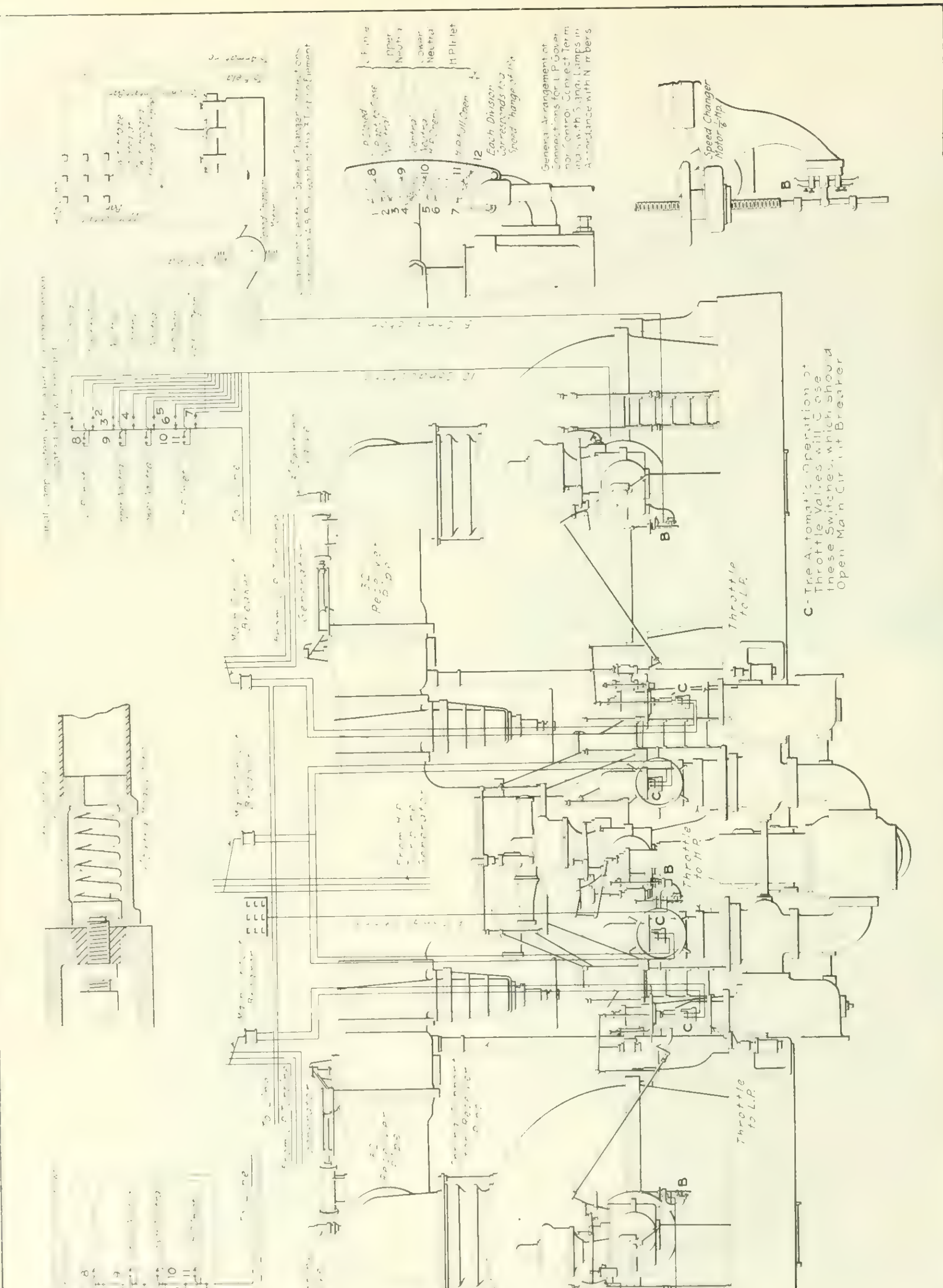


FIG. 21—SIGNAL CONTROL SYSTEM OF THREE-CYLINDER CROSS COMPOUND TURBINE UNIT

by a differential piston to both sides of which steam pressure is admitted. One end of this cylinder is connected to a valve trip mechanism located at the low-pressure governor and so arranged that when the governor reaches a prescribed position a valve will be

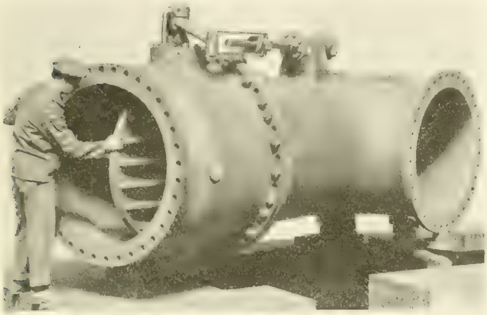


FIG. 22—AUTOMATIC VALVE

In receiver pipe between high-pressure and low-pressure turbines.

tripped open, thus releasing steam from that side of the differential position. Steam pressure in the other side will then quickly force the butterfly valve closed. If the turbine is to be shut down, the gate valve is then closed by hand. The butterfly valve may be opened or closed also by a hand-controlled valve.

The valve controlling live steam direct to the low-pressure turbine will begin to open when the low-pressure governor reaches a prescribed position. This valve mechanism does not differ in principle from the main high-pressure valve controlling steam in the system, and is in conformity with ordinary practice for such purposes.

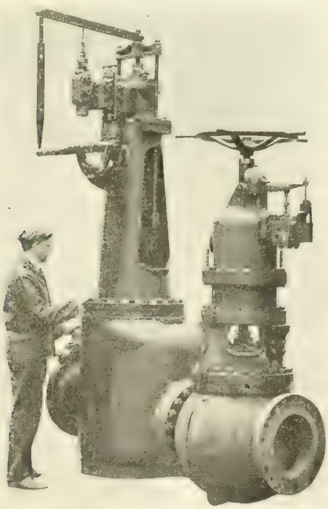


FIG. 23 LOW-PRESSURE VALVE GEAR

The overspeed stop governor on the high-pressure turbine will close the main throttle valve and the main regulating valve, while that on the low pressure turbine will bring about the closing of the butterfly valve, and the governor and throttle valves admitting high-pressure steam to the low-pressure turbines.

As part of the throttle valves there is a switch which, when closed, will open the main circuit breaker. Should some accident happen to one of the turbine elements, it may be instantly cut out by operating the emergency stop, which will cause the immediate closing of the automatic throttle. This in turn causes the closing of the switch, which opens the circuit breaker.

The operation of this apparatus may be further described by the following examples:—

1—If, on account of some electrical trouble, the circuit breaker opens between the generator of a low-pressure turbine and the bus, this turbine will then be relieved of load, and will speed up three percent (providing the governor has been maintained in the central position). Before it has speeded up four percent the low-pressure butterfly valve will have closed. In the meantime the steam is still going into the high-pressure turbine. The exhaust pressure of the high-pressure element will then rise, if the load be great enough, until the back pressure valve on the exhaust opens, permitting the high-pressure turbine to continue operating, a fraction of its steam exhausting into the atmosphere, the remainder passing to the low-pressure turbine which is in operation.

FIG. 24—60 000 KW RECEIVER PIPING

Upon closing the butterfly valve, the low-pressure turbine receiving no steam will commence to slow down, and when it has reached three percent below normal, the governor valve admitting high-pressure steam to the low-pressure element will commence to open and, unless some adjustment is made, it will remain at that speed under the control of its governor.

2—If an accident happens to a low-pressure turbine, making it desirable to take it out of service quickly, the operator can trip the emergency stop as he would on any turbine, which will cause the closing of the butterfly valve then admitting low-pressure steam, and the throttle valve which later would admit live steam to the low-pressure. The throttle valve being automatically closed by the emergency stop will close the switch, which will open the circuit breaker, when the low-pressure turbine will come to rest.

3—On a disturbance to the electrical system which will cause the opening of the circuit breaker on the generator of the high-pressure turbine, the high-pressure

turbine, being relieved of load, will speed up an amount corresponding to the regulating characteristics of the high-pressure governor, cutting off nearly all the steam supply to the whole system, only enough steam passing through the high-pressure element to maintain it at speed.

If there are enough units operating on the system to take the load that has been dropped by this unit, the low-pressure turbines will continue in service, but carrying practically no load. If, however, there are not enough units in the system to carry the load, then the frequency of the whole system will fall three percent (providing the low-pressure governor has been maintained in its central position) when high-pressure steam will begin to be admitted direct to the low-pressure turbines and a further fall of three percent will give complete opening to this governor valve, admitting high-pressure steam.

Should it then be found that the exigencies of the system demand that the low-pressure turbines continue carrying the load, the switchboard operator may then by his distant control of the governor tighten the governor spring by means of the motor until he brings the speed of the unit (and system) to normal, when the low-pressure turbines may continue operating indefinitely, carrying any load within their capacity with governor regulating the high-pressure valve opening.

4—In case of an accident to the high-pressure turbine, its emergency stop may be tripped, which will bring about the automatic closing of the main throttle valve. This valve, when automatically closed, will close the switch that is on the throttle valve, which in turn will open the main circuit breaker on the high-pressure turbine, after which the operation will be the same as in case *3*.

Since each low-pressure turbine has its independent governor, it is obvious that either or both will operate indefinitely if the high-pressure turbine has been put out of service as indicated in either *3* or *4* above.

If the throttle valve be manipulated by hand in the usual way it will have no effect on the switch that is on the throttle valve. This switch will only be closed when the throttle valves are operated by means of the emergency stop.

The general principle of multiple-cylinder turbines, each element driving a separate turbine, is by now quite old. It results in a great simplification of design. At first thought, such a machine may be considered complicated, by reason of the number of turbine elements with their additional bearings, etc. This is by no means the case, for turbine bearings are one of the elements that cause no concern. There is a direct gain in the factor of reliability by use of the cross-compound principle as is evidenced by the performance of the several two-cylinder machines which have been in operation for the past several years.

In the first conception of the cross-compound turbines the designer had in mind only the simplification and the reliability that would accrue therefrom. The possibility of operating the turbine elements individually was an obvious possibility, permitting energy to be produced in spite of an accident to one or other of the turbine elements, which became more apparent in the case of the three-cylinder machine. The unit partakes of the high efficiency corresponding to a large machine, and in a certain measure the flexibility of a number of small machines, permitting a given system to install larger machines with the same factor of reliability that would be good judgment were single cylinder units employed.

The foregoing description of the turbine is almost wholly devoted to describing the automatic features by means of which, in the event of trouble with any of the elements, it will be automatically cut out of service, the remaining two elements continuing to carry the load. This is because the particular feature is new while the turbines themselves present no unusual features which are not well known; the design being conservative, involving low stresses in all cases, permitting the use of readily obtained commercial materials. The question of being able to operate the turbine elements separately in case of emergency became one of great importance in the minds of some operating engineers, and therefrom came the demand that every advantage should be taken of this; and hence the development of the automatic apparatus herein described which obviously involves some complexity. Such arrangements, however, are by no means essential, for in the operation the turbine elements may be individually taken on and off the system manually with but little delay.

Lighting Without Hanging Ceiling Fixtures

A Tendency in Modern Lighting Methods

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THE illumination of interiors without the use of hanging ceiling fixtures is in many respects a new phase of lighting practice. The possibilities of this method have not been very generally discussed, although its applications are becoming more and more numerous. One finds in applying this method, that it takes many unexpected turns, it has many interesting and pleasing situations and is a means whereby many of the beautiful things in lighting may be realized.

We have by no means reached the highest standard in lighting practice and it seems that we are now coming into one of the important stages in the evolution toward the ideal in the art of lighting. Many milestones have marked the upward tendencies in this important activity, including the oil burner, the candle, the gas light and finally the modern electric lamp. Interesting stories have been written tracing the history of the lighting fixture through its various periods of utility and design. Today attention is more largely centered on the best uses of light for our comfort, our pleasure and our practical requirement. We have come to a place where we are now ready for the refinements in lighting methods and in the ways of using light.

FIG. 1- CORNICE LIGHTING EMPLOYED FOR A CHURCH INTERIOR

In the present day practice, especially in buildings of a public character, we are getting farther and farther away from the use of the so-called lighting fixture. Many experiences in recent installations have shown that ceiling fixtures are not always necessary. In fact, they often detract from the harmony of the interior. Although hanging fixtures have been used many years, there are numerous cases in which we need not confine ourselves to this arrangement.

There are many interiors that lend themselves especially to this new kind of lighting treatment. There are others in which the use of ceiling fixtures is precluded because of certain structural and architectural features. In any case, the lighting units can be worked into the decorative elements of the room, all lamps and reflectors being entirely hidden from view, yet flooding the interior with a clear comfortable illumination. The containers can be so designed that they will carry the suggestion of a decorative feature rather than that of a lighting fixture.

There are many methods by which the illumination of interiors without the use of ceiling fixtures can be accomplished. Units may be concealed in projecting coves or cornices, placed in wall boxes or pockets, in the caps of columns, hidden in the tops of floor pedestals, art lamps, on mantels, bookcases, in urns, etc. The method employed, of course depends upon the general character of the room to be illuminated.

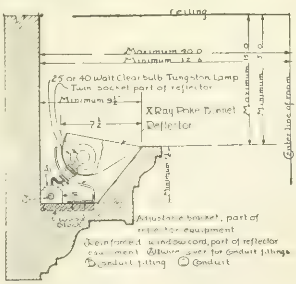

FIG. 2 CORNICE SECTION

The correct application of this phase of lighting practice calls for very careful planning and co-operation on the part of the lighting man, the architect and contractor. There are a number of instances in which architectural design has been modified to conform to the lighting plan, but without compromising in any way, the decorative and architectural features of the interior. In some cases, it is even necessary to design special reflectors in order to properly direct and control the light. Great variety in lighting effects are possible because of the flexibility that characterizes this method. Its applications are almost unlimited in extent. This method is used in stores, display rooms, offices, in the home and in many other places where on first thought hanging ceiling fixtures might be considered the only

practical method.

The degree to which this method of illumination has been employed in the past two or three years, leads us to predict that much of the lighting of the future will be accomplished from sources entirely concealed and without resorting to the use of hanging ceiling fixtures. This does not mean however that there are not many interiors in which fixtures are most appropriate and will continue to be used, as for instance, interiors of a commercial type and those wherein, for certain artistic reasons, the designer wishes to retain the suspended fixture.

FIG. 3—COVE LIGHTING
An appropriate method for lighting motion picture houses.

FIG. 4—LIGHT REFLECTED FROM THE TOPS OF CASES AND PARTITIONS
A dignified effect can be obtained as shown in this New York store.

The chief aim in this article is to point out some of the practical methods that have been employed and to suggest some of the possibilities in lighting where the ordinary ceiling fixtures are not used.

COVE LIGHTING

The lighting of interiors from coves and cornices is one of the oldest forms of illumination without ceiling fixtures. This method was applied in the early days of the incandescent lamp and there is also a record that cove lighting was used many years ago with gas and even oil lamps. The early installations of cove lighting were necessarily very inefficient, as the light was poorly controlled and the waste was enormous. Cove lighting can now be installed that compares favorably with systems using ceiling fixtures, thus making it a practical method of illumination for many interiors such as churches, auditoriums, theaters, ballrooms, lobbies, and even residences.

FIG. 5—INTERIOR VIEW OF A STORE IN PASADENA, CALIFORNIA
The lighting method employed is the result of the cooperative effort of the architect, interior decorator and lighting man.

The church auditorium in Fig. 1 receives all of its illumination from a cornice along two sides of the room. The equipment used is shown in a diagrammatic way in Fig. 2. The lighting units are spaced two feet apart and each unit contains two 40 watt lamps. The design of the reflector employed is such as

FIG. 6—AN AUTOMOBILE SALESROOM LIGHTED WITH A CLUSTER OF UNITS AROUND THE COLUMNS

to throw the light away from the walls toward the center of the ceiling. In some installations of this character, the cove is so small that a special reflector shape is required.

In cove lighting, the ceiling should be uniformly illuminated. Splashes of light or alternate light and dark spots on the wall just above the equipment must be avoided. The size and extent of the cove, its proximity to the ceiling of the room, the means of reaching the cove for cleaning and renewing of lamps are all factors which must be carefully considered in the design of a cove lighting system.

LIGHTING FROM TOPS OF CASES AND PARTITIONS

A store in New York City utilizes the tops of display cases and partitions for the illumination of a salesroom, as shown in Fig. 4. Ceiling fixtures are entirely absent. In fact, there is no suggestion as to the location of the light sources except for the artistic touch of a few portable lamps, seen in the illustration. An unusually uniform ceiling effect is obtained by the careful placing of the reflecting units.

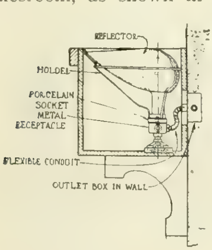

FIG. 7—SECTIONAL VIEW OF A WALL LIGHTING BOX

Showing the special design of the reflector unit employed.

LIGHTING FROM COLUMN CLUSTERS

One of the advantages of the lighting methods shown lies in the fact that it leaves the ceiling clear and gives the interior a more roomy appearance. Indirect lighting makes the ceiling appear higher, a very desirable feature in many cases, especially for rooms having a low ceiling. Fig. 5 shows a view in a California store where a special reflector unit was employed in brackets on each column.

An installation in an auto display room, such as the one shown in Fig. 6 has the advantage of attractiveness aside from the fact that the illumination is remarkably well diffused and especially good for the displaying of the highly finished surfaces of the cars.

FIG. 8—WALL BOX OR WALL POCKET METHOD OF ILLUMINATION

An effective and inexpensive method of lighting a salesroom.

Beautiful finishes and polished articles are most advantageously displayed under diffused lighting. Direct light tends to produce shadows, reflections and spots where in reality, they do not appear on the surface, thus showing up the product in an inferior way. A lighting system which will combine the desirable features of indirect illumination and at the same time have advertising value, because of its unusual or unique appearance, is greatly to be desired. The illustration in Fig. 6 shows clearly the method employed with a cluster of lighting units around each column near the ceiling. This particular room is 46 feet wide and 97 feet long; the ceiling is 16 feet high. Each of the ten columns supports a cluster containing eight re-

FIG. 9—SOLARIUM IN A COUNTRY CLUB HOUSE

Illuminated solely from one central floor pedestal containing five 500 watt lamps in mirrored reflectors.

flectors, each with a 75 watt lamp. In combination with these units, wall boxes containing special reflectors with 100 watt lamps are employed. The total wattage per square foot is two. It is six feet from the ceiling to the top of the boxes and clusters.

WALL BOXES AND POCKETS

Many times it is not practical to construct a continuous cove for the concealment of the lighting units, but yet it is desired to illuminate the interior by means of hidden reflectors. To meet this condition, a scheme known as the wall box method and a special reflector designed for use in these boxes has been advantageously employed. The sectional diagram, Fig. 7, shows a wall box in which the special reflector has been installed. This reflector because of its peculiar shape can be placed almost directly against the wall and still not allow the light to splash on the area above the unit. The light is projected to the ceiling away from the wall, therefore eliminating the annoying dark and light areas which would ordinarily occur if the special reflector were not used. Fig. 8 shows a practical application of this method in an automobile salesroom. The wall boxes in this instance have been worked into the paneling and occur at each pilaster.

The wall box method is an especially good one for the lighting of theater auditoriums. It permits of a clear unobstructed view from one end of the room to

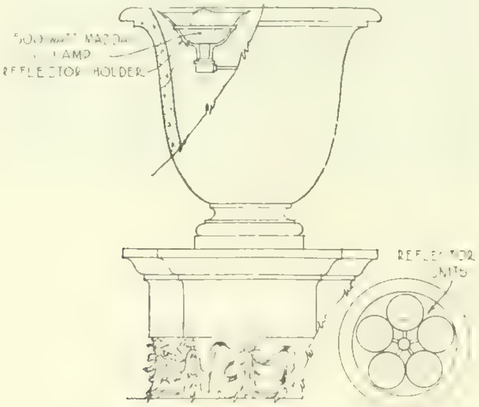

FIG. 10—DETAIL OF THE PEDESTAL IN FIG. 10

the other, and since the hanging fixtures are eliminated, there is no interference to the projection of pictures. Where the architectural treatment of the interior does not lend itself to the use of a continuous cove, the wall box scheme is an ideal method.

The usual proceding in theater lighting is to provide three or four units in each box. The units are wired on separate circuits, thereby providing several intensities of illumination and adding to the flexibility of the installation. With one lamp or unit in each box burning, a dim illumination is provided while the show is in progress. By turning on more lamps, a brighter light may be secured for intermissions.

The use of this method and also that of cove lighting in theaters makes possible the application of color lighting. Color screens can be mounted above each of the lighting units, and with the units arranged on various circuits, one for each color, the atmosphere of the interior may be entirely changed by means of a varying tint to the illumination. A system of dimmers in circuit with the lighting units provides an easy means by which the auditorium may be lighted so gradually that one is scarcely aware of the increasing intensity. Then the colors of red, green, blue or amber or various combinations can be passed through to a direct white, gradually receding to almost actual darkness without a noticeable flicker. Many of the most modern theaters have been definitely planned with the idea of making color effects a part of the lighting scheme using a cove lighting or other method by which the ceiling fixtures are discarded.

PEDESTAL LIGHTING

Indirect lighting of interiors from floor outlets has been employed not only where novel lighting effects are desired but also where illumination of the entire room from one central location is desired. In the case of floor pedestal lighting as shown by the illustrations of Figs. 9 and 11, the lighting standards are for all intents and purposes merely decorative receptacles for flowers. If the proper equipment is installed, it will not be at once apparent that the light emanates from the bowl in the pedestal. Careful ad-

FIG. 11—PEDESTAL METHOD OF LIGHTING TEA ROOMS, CONFECTIONERY STORES AND SIMILAR INTERIORS

justment is necessary in making an installation of this character to insure that the entire ceiling is evenly illuminated and to prevent sharp contrast between the ceiling and sidewall illumination.

The details of the lighting standard for the solarium shown in Fig. 9 are given in the diagram of Fig. 10. The bowl which surmounts the pedestal or lighting standard contains a number of reflectors and lamps. The area illuminated is 43 feet square, the ceiling height is 21 feet, the lighting standard 10 feet high and 36 inches across the top of the urn. This urn contains five 500 watt lamps in mirrored reflectors. The wattage consumption is about 1.3 watts per square foot. In this room, for ornamental purposes only, lantern type fixtures are suspended from the ceiling in the side bays or wings, containing low wattage lamps. Beautiful color effects are produced in the solarium space by placing color screens above the reflector units.

ART LAMPS

One of the most novel and attractive devices for

the illumination of rooms, especially rooms in the home, is that of the indirect lighting portable lamp. This lamp performs two purposes as is clearly illustrated by Figs. 12 and 13. It will provide light immediately under the lamp with the effect obtained by the ordinary table lamp. It will also, by the pull of a switch, flood the entire room with diffused indirect illumination. The entire mechanism for producing

FIG. 12—ILLUMINATION FROM AN ART LAMP AS IT IS USUALLY EMPLOYED

For localized lighting near the table.

these effects is concealed within the silk shade of the lamp so that the appearance of the lamp remains unchanged. Fig. 14 shows the shade of a table lamp partially cut away to expose the mechanism. This mechanism consists of a large reflector which provides the indirect illumination, small lamps at the base of this reflector, and switches for controlling the lights. By pulling one switch, the small lamps are lighted, giving the shade the illuminated decorative effect of the

FIG. 13—SAME ROOM AS SHOWN IN FIG. 12 ILLUMINATED WITH A FLOOD OF INDIRECT LIGHT

The light comes from special equipment concealed inside the shade. This lighting effect can be alternated with that shown in Fig. 12 by the pull of a switch.

usual art lamp and providing the light on the table for ordinary reading purposes. When a general illumination in the room is desired, the pulling of another switch turns on the large Mazda lamp contained and hidden within the opaque reflector. The light from this lamp and reflector is thrown to the ceiling and then diffused throughout the room as indirect illumination.

The indirect lighting art lamp has a wide adaptability. It has been used primarily for illumination in the home, but is also recognized as an ideal method for the illumination of candy shops, millinery shops, beauty parlors, and tea rooms. The ordinary art lamp, although it has found great favor in the American home, has in many instances little or no value from a utilitarian standpoint. The most pleasing effects are obtained from this indirect portable lamp. It provides a flexibility in the illumination of the home, allowing for a variation of the monotony in lighting.

CURRENT CONSUMPTION

When properly installed indirect lighting equipment gives economical results, comparing favorably with the direct or semi-direct methods. In many cases, indirect illumination has been employed at a saving in current and wiring costs over an adequate direct lighting system for the same interior. This is due to the

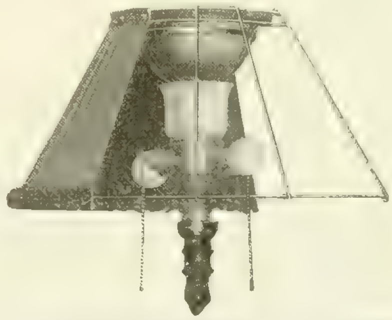

FIG. 14—INDIRECT PORTABLE LAMP ADAPTER

The mechanism is entirely concealed within the silk shade so that the outward appearance of the lamp remains unchanged.

fact that the lighting units can be concentrated at a few central locations, thereby cutting down the number of outlets. Also the diffuse character of the illumination makes it possible to light large areas fairly uniformly from one fixture. It often occurs that due to the greater ability to sustain clear seeing under indirect illumination, less wattage can be used than by direct or semi-direct lighting.

Current consumption should not and does not form the basis for a fair comparison of any two or more systems of lighting for any interior. Items such as psychological and physiological effect, cost of maintenance and upkeep, first cost of wiring, fixture cost, architectural and æsthetic advantages, as well as the seeing ability under the systems should form the real basis for comparison. Until recently, the question of cost was usually decided upon current consumption instead of greatest human efficiency under the system.

For the systems described in this article, cove lighting and installations employing column clusters usually require a little more wattage than indirect lighting with ceiling fixtures, whereas the floor lamps and pedestals need not have a greater wattage consumption than a fixture installation.

Electrically-Driven Plate Mills

Of the Brier Hill Steel Company

G. W. Haney
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Brier Hill Steel Company

THE problems encountered in the application of electric drive to the great variety of machinery employed in the manufacture of steel products are probably more diversified than those which arise in the use of electricity in any other industry. Among the plants in which the electrical and mechanical features have been worked out with considerable detail is the new plate mill of the Brier Hill Steel Company at Youngstown, Ohio, in which electric drive is used throughout. The plates, which are the sole product of the plant, are rolled in two mills; one a three-high, one-stand mill, having a width of 132 inches, and the other a two-stand mill 84 inches wide. The roughing stand of the 84 inch mill is driven by a reversing direct-current motor supplied with energy from a flywheel motor-generator set, and the three-high finishing stand is connected to a continuous running alternating-current motor rated at 2500 hp. A 5000 hp, alternating-current motor drives the 132 inch mill.

A general layout of the entire plant is given in Fig. 2. The equipment is in one large building, 1350 feet long. The part of the building in which the finished plates are sheared, weighed and stored, or shipped, is built of brick and is 312 feet wide and 394 feet long. The remainder of the building is of structural steel construction, and has a width of 208 feet. Slabs are brought into the upper end of the building on two standard gage tracks and transferred from the cars to the storage piles by equipped magnet cranes.

There are three continuous furnaces for each mill. These furnaces burn gas from the Company's coke ovens located at the main steel plant some distance away. Cranes carry the slabs from the storage piles to electrically-operated pushers located at the rear of each furnace. Hot slabs are discharged from the front of the furnaces onto the mill approach tables. After a plate has been rolled in the 132 inch mill, it goes through a straightener and then runs out on a chain cooling bed. From the cooling bed, it passes to an inspection table and on to the various shears at the lower end of the building. Plates rolled in the 84 inch mill may go either directly to a straightener, inspection table, and shears, or through an annealing furnace and then to be straightened, inspected and sheared.

All power for operating the plant is supplied by the Republic Railway & Light Company through two three-phase, 60 cycle, 66 000 volt lines which are connected through oil circuit breakers and disconnecting switches to the Power Company's 66 000 volt bus at the generating station at Lowellville, Ohio. By the side of the Steel Company's mill and within the property line of the plant, there has been erected an outdoor substation which, in its layout and construction, represents modern engineering practice both in the application of the high-voltage substation to steel mill requirements and to power plant distribution systems.

FIG. 1—OUTDOOR SUBSTATION
Brier Hill Steel Company's stepdown transformers at extreme left. The brick ducts through which the secondary leads extend to the tunnel below can be seen behind the transformers. The 22 000 volt lines pass over the mill from the structure nearest the building. The 66 000 volt structure is at the right.

The construction of the substation is shown in Fig. 1, and the main connections are shown by the single line diagram, Fig. 3. The two 66 000 volt lines connect to a main and auxiliary bus which is supported in the structural work by substantial insulators of the suspension type. The bus arrangement allows enough flexibility in switching to enable any piece of apparatus which may be damaged, to be cut out of circuit and repaired or replaced without the necessity of discontinuing the main functions of the substation.

Part of the power transmitted over the 66 000 volt lines is transformed to 22 000 volts and is used by the Power Company in their 22 000 volt distribution system, which is connected to this substation through the four 22 000 volt lines shown on the single line diagram. The 22 000 volt system is so arranged that if, for any reason, power cannot be furnished to the Steel Company over the 66 000 volt lines, it can be supplied through the medium of the 9375 k.v.a. transformer banks from the 22 000 volt system, thus insuring a constant supply of power to the Steel Company. All circuit breakers are electrically operated and are controlled from the control desk in the mill substation.

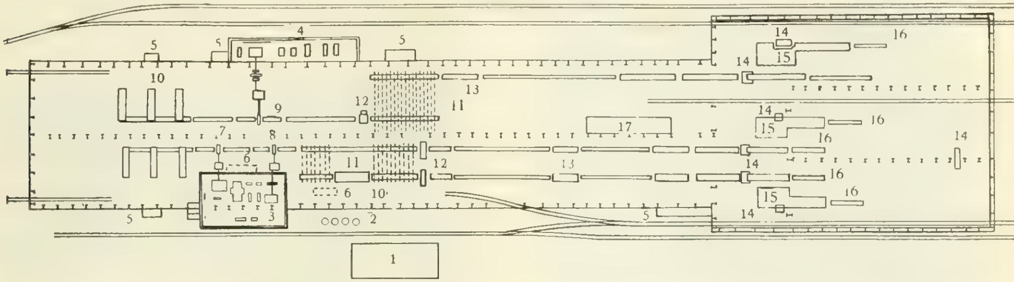

FIG. 2—LAYOUT OF PLATE MILL

1—Republic Railway & Light Co.—outdoor substation; 2—Step-down transformers; 3—Substation; 4—Motor room of 132 inch mill; 5—Control houses; 6—Control cellars; 7—Roughing stand—84 inch mill; 8—Finishing stand—84 inch mill; 9—132 inch mill; 10—Furnaces; 11—Chain transfers; 12—Straighteners; 13—Inspection tables; 14—Shears; 15—Castor bed; 16—Scales; 17—Roll shop.

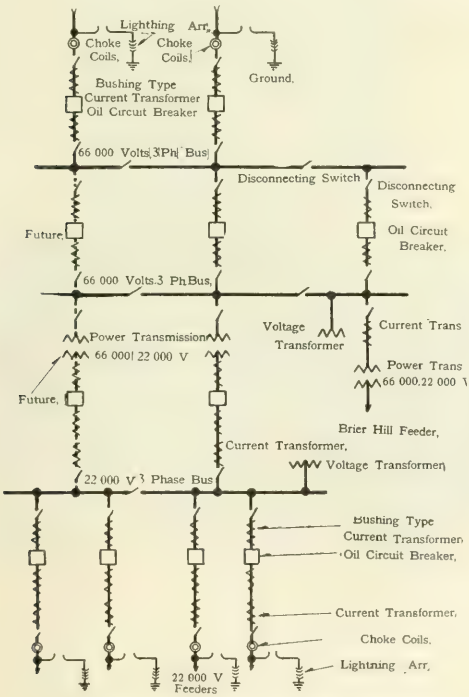

FIG. 3—SINGLE LINE DIAGRAM OF OUTDOOR SUBSTATION

Power is supplied to the mill through a bank of three 3500 k.v.a. 66 000/2200 volt single-phase oil insulated self-cooled transformers. One additional transformer is kept as a spare and all transformers are mounted on wheeled trucks so that any defective transformer may be removed and the spare transformer substituted with a minimum of time and effort.

The total power supplied to the mill is metered on the 66 000 volt side of the supply, there being furnished as metering equipment a graphic wattmeter, a graphic power-factor meter, and a combined watthour meter and graphic watthour demand indicator. The readings of all these meters are taken into consideration when the charge for the energy consumed is determined.

FIG. 4—OIL CIRCUIT BREAKERS IN MOTOR SUB-STATION BASEMENT

Connections on the 2200 volt side of the transformers are made of bare copper strap, and these straps are run through brick ducts into a tunnel containing the main bus extension, where they form a closed delta connection and are joined to the bus. In the tunnel, the bus is supported by a substantial pipe framework on which the bus insulators are mounted.

The tunnel leads to a bus and circuit breaker structure which extends nearly the full length of the motor substation basement. In one side of the structure are located the bus and feeder compartments and the neces-

sary disconnecting switches for the various circuits of the plant. The oil circuit breakers with their operating mechanisms are mounted on the other side. Circuit

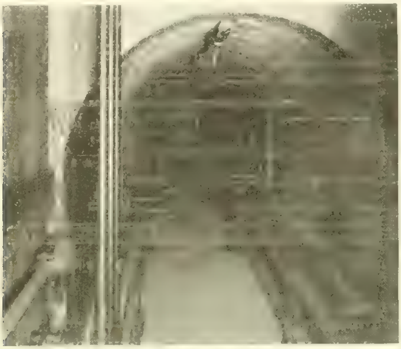

FIG. 5—2200 VOLT FEEDER TUNNEL

breakers of large rupturing capacity are used on account of the large capacity of the power system to which the plant is connected, which would cause very heavy currents to flow in case of an accidental short-circuit on any of the 2200 volt feeders. Fig. 4 gives a view of the circuit breaker structures showing the construction of the cells and the mounting of the operating mechanism. Operation of the circuit breakers is effected from the control desk in the motor room above.

A waterproof tunnel extends from the main sub-

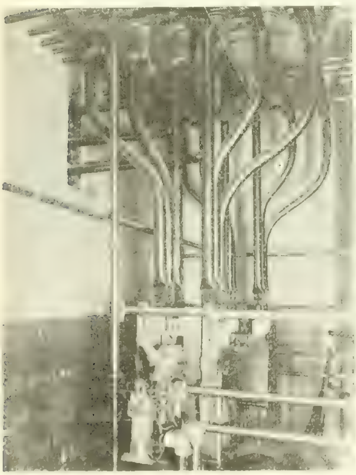

FIG. 6—OIL CIRCUIT BREAKER FOR 5000 HP MOTOR

Showing neat appearance of connections which can be obtained when tubular conductors are used.

station basement to the basement under the motor room of the 132 inch mill. The view shown in Fig. 5, which was taken at the point where the tunnel enters the 132 inch motor room basement, shows the construction and method of mounting the two 2200 volt feeders carried in the tunnel. The feeder on the left is made up of 1.25 inch copper tubing and supplies the pump and air compressor motors located in the room above. The other feeder, which is constructed of 2.5 inch copper tubing, is connected to the 5000 hp motor driving the 132 inch mill. The use of tubular conductors re-

FIG. 7—GENERAL VIEW OF MOTOR SUBSTATION

The control desks are shown in the left foreground. The rear panels carry graphic and integrating meters and no-voltage and overload relays. Sections of the roof over the heavy equipment may be removed, allowing the mill crane to be used in lifting parts.

sults in a material reduction in the weight of copper required, especially on a 60 cycle circuit where the skin effect would make the amount of inactive material quite appreciable if copper straps or solid circular conductors were used. The oil circuit breakers for the 5000 hp motor are shown in Fig. 6.

In the main motor substation, Fig. 7, are installed the reversing motor and its flywheel motor-generator set, exciter set, circuit breaker and control panels; the 2500 hp induction motor; two 750 kw synchronous motor-generator sets; the motor-generator set for the con-

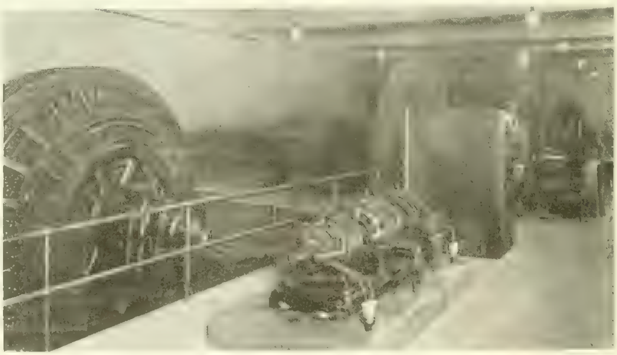

FIG. 8—REVERSING EQUIPMENT DRIVING THE ROUGHING STAND OF THE 84 INCH MILL

Showing arrangement of Westinghouse reversing motor, flywheel motor generator set, exciter set, and direct-current circuit breaker panel.

trol circuits; two liquid slip regulators and the main control desks. The heavy pieces of equipment can be lifted with the mill cranes by taking off sections of the motor room roof. During the day, the room is unusually well lighted through numerous large windows and at night illumination is supplied by enclosed nitrogen lamps hung from the roof and mounted on steel columns. Two of the lamps near the control desks

are supplied from the control storage battery, thus preventing total darkness in the room if the voltage of the alternating-current system fails.

The reversing motor which drives the roughing stand of the 84 inch mill, Fig. 8, has a maximum rating of 1 000 000 foot-pounds torque at 40 r.p.m. Commutating poles and compensating windings are provided and the 600 volt armature is designed to give the least possible rotative inertia. The main field is compound wound, thus increasing the motor torque for heavy passes, and allowing the speed to increase during light passes. The shunt coils are energized by a 125 volt constant potential generator and the compounding winding is supplied from a variable potential generator, the voltage of which is proportional to the current in the motor armature. Reversal and speed control are obtained through manipulation of the field of the generator of the flywheel motor-generator set. The motor is quickly brought to rest by regenerative braking. This feature makes it possible to reverse from 40 r.p.m. in one direction to 40 r.p.m. in the opposite direction in two seconds. The automatic magnetic contactor controller, Fig. 9, is operated from a master switch in the mill pulpit. A blower and air washer located in the basement of the substation provides forced ventilation for the motor windings. About 35 000 cubic feet of clean air per minute is supplied through a carefully laid out tunnel under the basement floor.

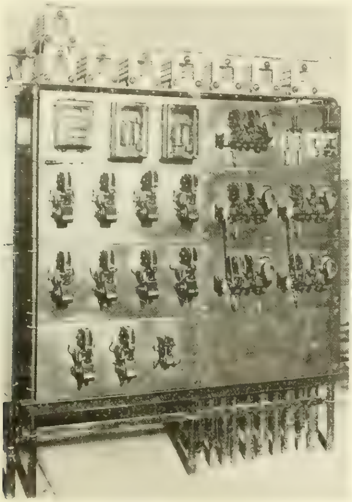

FIG. 9—MAGNETIC CONTROLLER FOR REVERSING MOTOR

The flywheel motor-generator set of the reversing equipment consists of a 1500 hp, three-phase, 60 cycle, 2200 volt, 350 r.p.m. induction motor; a 60 000 pound flywheel and a 2250 kw, 600 volt, shunt-wound separately excited direct-current generator having commutating poles and compensating windings. Excitation is obtained from the constant potential generator of the exciter set. A liquid slip regulator in the secondary of the motor equalizes the input. When the load reaches a certain value, the regulator introduces resistance in the secondary which causes the motor to tend to drop in speed, thus allowing the flywheel to give up some of its energy, and absorb the sharp peaks. When the load goes off, the regulator gradually decreases the resistance and the flywheel is brought back to full speed.

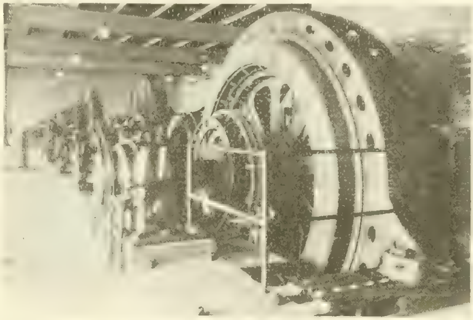

FIG. 10—2500 HP ALTERNATING-CURRENT MOTOR DRIVING 3-HIGH FINISHING STAND OF 84 INCH MILL

The two 750 kw synchronous motor-generator sets and the flywheel motor-generator set appear in the background.

The three-high finishing stand of the 84 inch mill is driven by a 2500 horse-power, 2200 volt induction motor through single reduction gearing in the pinion housing. A heavy flywheel is mounted between the motor and pinion housing. A liquid slip regulator is used which equalizes the input to the motor and allows the flywheel to absorb the peaks.

The use of the roughing stand reversing, and the finishing stand three-high continuous running in tandem is a very desirable combination. In case of a breakdown in the finishing mill, the total reduction may be made on the roughing mill, thus keeping the plant from having to shut down completely. The two-high mill driven by a reversing motor is inherently adapted to the first roughing passes. The reductions are heavy and the slab is narrow and requires careful manipulation in order to insure its going through the mill straight. The ease and rapidity with which the reversing motor can be started, stopped or reversed, makes the manipulation of the slab rapid and safe, and

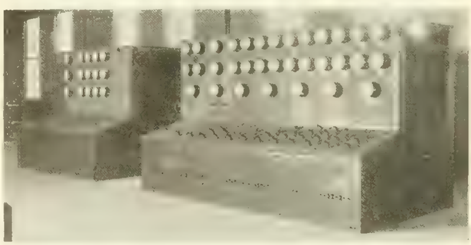

FIG. 11—CONTROL DESKS

The desk at the left controls the high-tension switches in the outdoor substation. The oil circuit breakers shown in Fig. 4 are operated from the desk at the right.

very materially reduces the interval between passes, thus reducing the total rolling time. The reversing motor can be operated over a wide speed range, and each pass can be made at the speed best suited for it; thus reducing the duration of the passes to a minimum.

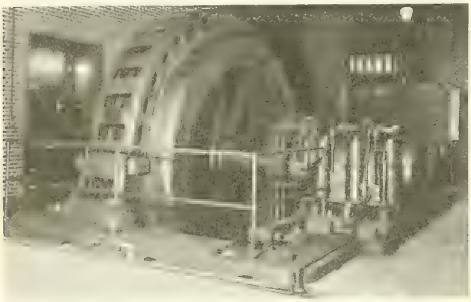

FIG. 12 5000 HP MOTOR DRIVING 132 INCH, 3 HIGH MILL
The liquid slip regulator is shown in the background.

During the finishing passes, the plate is long enough to require little or no manipulation and can be rolled at a higher speed. For this kind of operation, the three-high continuous running mill is particularly adapted.

Power for operating the auxiliary motors of the plant is supplied from two 750 kw, 250 volt direct-current, 2200 volt alternating-current synchronous motor-generator sets. The synchronous motors each have a capacity of 1050 k.v.a. at 80 percent power-factor, and are run over-excited to give power-factor correction. The panels carrying the circuit breakers and integrating meters for the various direct-current feeders are in the basement. The circuit breakers are operated from the control desk and recording dials on the rear panel of the desk show the reading of the integrating meters, making it unnecessary for the operators to visit the basement to take readings.

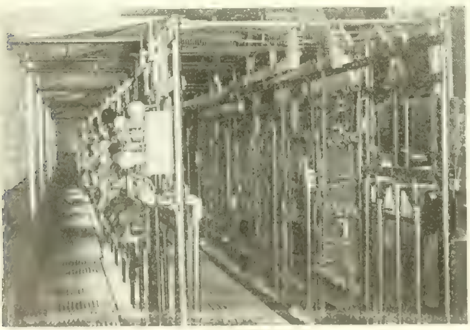

FIG. 13 ONE OF THE SEVEN AUXILIARY CONTROL HOUSES
Showing two rows of Westinghouse panels mounted back to back with resistors on racks above. The 230 volt bus extends behind all the panels.

There are two control desks, as indicated by Fig. 11, one of which belongs to the Brier Hill Steel Company and the other to the Republic Railway & Light Company. The latter desk has on its front side the control switches for operating the oil circuit breakers in the outdoor substation and the necessary indicating meters. On the rear panel are located the graphic and integrating meters. The other desk controls all the alternating-current and direct-current circuits of the plant. The front side carries the various indicating meters and on the rear panel are mounted the graphic and integrating meters and the over-load and no-voltage relays. Energy for operating the circuit breakers and pilot lights is normally supplied from a small motor-generator set, having a 125 volt generator driven by a 250 volt direct-current motor. A 60 cell storage battery which is charged from the 250 volt circuit through resistance is used for the control circuits in emergencies.

In the motor room of the 132 inch mill are located the 5000 horse-power motor driving the three-high mill, two electrically-driven air compressors, three motor-driven high-pressure hydraulic pumps, and the necessary control apparatus. The oil switches are in the basement. The 5000 hp motor shown in Fig. 12 has the same general characteristics and construction as

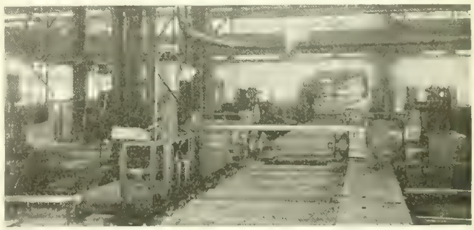

FIG. 14 ELECTRICALLY DRIVEN ROTARY PLATE SHEAR

the one driving the finishing stand of the 84 inch mill. Its speed is 197 r.p.m., and it drives the mill through reduction gears in the pinion housing. A flywheel and liquid slip regulator equalize the peaks on the motor.

The various auxiliaries of the plant, such as cranes, roll tables, lift tables, conveyors, screw-downs and slab pushers are driven by standard 230 volt direct-current enclosed mill type motors. The automatic magnetic controllers for these motors are grouped in five lean-to houses and two control cellars. This arrangement affords excellent protection from dust and mechanical injury, and still makes the control accessible for adjustments and renewals. Fig. 13 shows the arrangement of the control panels, the resistors and the common 230 volt bus supplying the various motors controlled by these panels in one of the lean-to houses.

Among the more interesting auxiliary motor applications of the plant are the rotary trimming shears, Fig. 14. The 84 inch mill has two of these shears and there is one for the 132 inch mill, as indicated by the mill layout in Fig. 1. Both sides of the plate are trimmed at once. Two motors are used, one for driving the cutters and one for adjusting the cutters for various widths of plate.

Temperature Indicators for Alternators

S. L. Henderson

THE high standard of continuous service which central stations aim for and the use of the modern high capacity generating units make it necessary to pay strict attention to the maintenance and operating conditions of the generating equipment. The cost of repairs on large generators on a percentage basis may be no larger than on smaller units, yet repairs take longer and are harder to make, and furthermore the shut-down of one of these large units is felt more seriously, since each unit is a large percentage of the station output.

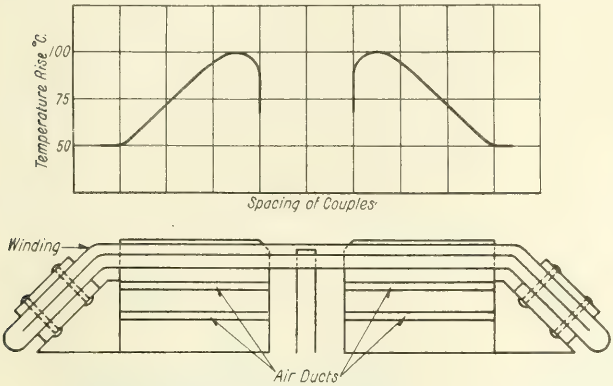

FIG. I—TEMPERATURE RISE ACROSS THE CORE OF AN AXIALLY-VENTILATED MACHINE

As an aid in keeping in close touch with the operating conditions of these large generators, temperature detectors have been developed which give a means of determining more closely what the operating temperatures are than is possible with thermometers on the end windings.

Considerable study and research work was necessary in order to know just where these detectors should be located in the generator, in order to read the highest temperature it was possible to measure. The heat distribution in one of the larger generators is a complex problem, but in general the buried portion of the coil is hotter than the ends, because this part of the coil is surrounded by iron which is hotter than the cooling air which blows over the ends. In most types of ventilation, excepting those which admit air at the center of the machine, the buried copper midway between the ends will be the hottest, for the reason that the temperature of the cooling air which reaches the center of the machine is already raised by the heat picked up due to friction, windage, and iron losses. Consequently, the copper temperature is increased a corresponding amount if the coil is to get rid of its heat. Fig. 1 illustrates in a general way the temperature gradient in an axially ventilated machine and Fig. 2 that in a radially ventilated machine. It has been found, as the result of a large number of tests, that if one of these detectors is placed in the center of the generator between the top and bottom coils, as shown in Fig. 3, the temperature observed will be the maximum which it is possible to measure safely. Laboratory tests have been made with the detector against the bar copper, but this cannot be recommended for practical testing because, even though placed on the neutral coils, it might be possible to have a dangerous voltage to ground due to line disturbances. Variations in design affect the exact location of the hot spot and it must be left to the judgment of the manufacturer, who is constantly obtaining data on temperatures, as to just where the detector should be placed.

The detectors should be rugged and easily placed in the machine without possibility of injury. They should be insulated to stand any temperature with which they are likely to come in contact, to prevent their becoming worthless after a time, due to short-circuits within themselves. Fig. 4 is a view of a pair of these detectors.

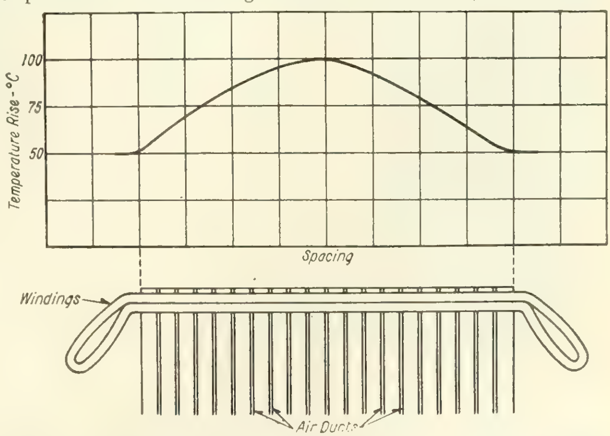

FIG. 2 TEMPERATURE RISES ACROSS THE CORE OF A RADIALLY VENTILATED MACHINE

There are two general methods of measuring temperatures by detectors known as the exploring coil method and the thermo-couple method.

EXPLORING COILS

The simplest exploring coil method is one which employs the Wheatsone bridge arrangement in which the fourth arm of the bridge consists of a resistance coil embedded in the armature winding. This coil is wound on a strip of mica using a large number of turns of small wire. The finished coil is about five inches

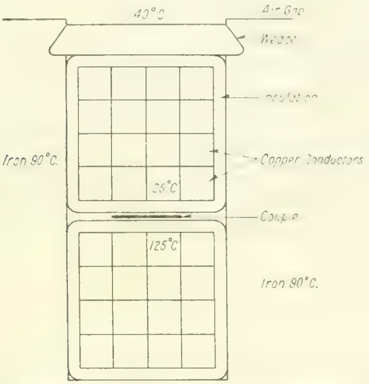

FIG. 3—THE PROPER LOCATION OF THE DETECTOR IN THE ARMATURE SLOT

long and one-sixteenth inch thick and has a resistance of approximately 30 ohms. This resistance must be kept high so that the resistance of the leads will be small in comparison.

The other three resistances completing the bridge are located at the switchboard. The value of these three resistances is such that when the temperature of the exploring coil has reached some predetermined value the bridge is in balance and there is no difference in voltage between points *3* and *4*, Fig. 5. At any other temperature there is a difference in voltage between these two points, but within the range of temperatures obtained the error from this cause is slight. A standard type of voltmeter is used with a scale laid off in degrees. Any constant source of direct-current current is sufficient and if this is above 20 volts a series resistance is furnished. The value of the resistance is generally such that when the exploring coil is at

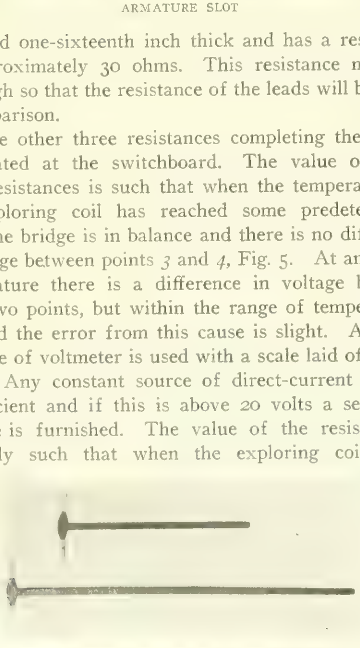

FIG. 4—TWO LENGTHS OF THERMOCOUPLES

90 degrees C. the instrument is at zero deflection and this point is marked 90 degrees C. Care must be taken that the impressed voltage is held at the value for which the series resistance was furnished, otherwise the indications will be in error on readings other than 90 degrees C.

The exploring coils are expensive to make, not only on account of the number of turns of small wire, but also on account of the amount of testing and adjustment required to secure the proper resistance. They are also subject to short-circuits and open circuits when they are placed in the machine.

The complete equipment necessary for use with exploring coils will consist of:—

1—The exploring coils, usually six per generator.

2—A terminal board on the generator frame, usually located near the main leads for convenience, and to which the individual coils are connected.

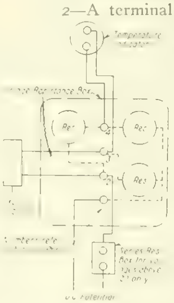

FIG. 5—WHEATSTONE BRIDGE METHOD OF TEMPERATURE MEASUREMENT

3—A multi-conductor cable used for connecting the individual coils to the instrument. (It is customary to connect one side of all the coils to a common lead so that if six coils were used a 7-conductor cable would be necessary. One side of the circuit is preferably grounded for protection of the operator and to eliminate all possibility of any static affecting the accuracy of the meter.)

4—A dial switch located near the instrument and used to connect the coil on which the measurement is desired to the meter.

5—A suitable meter, usually arranged for switchboard mounting, together with the resistance box containing the three permanent resistances referred to in the preceding paragraphs, and when the source of supply exceeds 20 volts an additional resistance of suitable value to cut down the voltage from the source of supply to less than the predetermined figure of 20 volts maximum.

In using this equipment it is not good practice to leave any one exploring coil permanently connected in the circuit since the effect is to heat the exploring coil, with a possibility of burning it out in time.

Another exploring coil method used as standard by another manufacturer is outlined in Fig. 6, and is a balanced resistance method. The detector is a coil wound with copper wire, which has a resistance of approximately 10 ohms and is approximately 10 inches long. Three leads are run from each detector to the switchboard. The resistance R_1 and the resistance of the temperature coil are alike at some given temperature, say 80 degrees C. The resistance R_1 has a zero coefficient (i. e. its resistance does not vary for changes in temperature). The temperature coil has a positive coefficient (its resistance increases with temperature). The two coils in the instrument C_1 and C_2 are wound differentially. An external source of current supply is required and is usually 125 or 250 volts. The adjust-

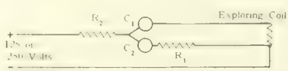

FIG. 6—BALANCED RESISTANCE METHOD OF TEMPERATURE MEASUREMENT

able resistance R_2 is used to modify the current when the voltage varies from normal.

When the resistance of the temperature coil and the resistance R_1 are alike, the current is equal in coils C_1 and C_2 and the instrument is not deflected. As the temperature of the machine increases, the resistance of the temperature coil increases, and the current of this

arm in series with coil C_1 becomes less than the current through C_2, and the coil is deflected.

The principle of operation is quite different for these two exploring coil methods, and while they both make use of a resistance coil, the instrument of one cannot be used with the temperature detectors of the other.

THERMOCOUPLES

The thermocouple method depends on the fact that a difference of electrical potential exists at every junction between dissimilar metals. In a closed circuit made up of two dissimilar metals there must obviously be two junctions. If these two junctions are at the same temperature the two e.m.f.'s will be equal and opposite and no current will flow in the circuit. If, however, one junction is maintained at a different temperature from the other there will be a difference in the e.m.f. that throughout the range of temperature encountered in electrical machinery will be proportional to the temperature difference. The method, therefore,

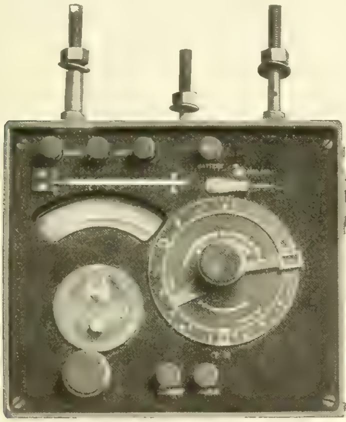

FIG. 7—SWITCHBOARD TYPE POTENTIOMETER OR TEMPERATURE INDICATOR

in its simplest form requires a hot and a cold couple and a device for measuring the difference in electromotive force between the two couples.

The couples are made by welding copper and advance (nickel-copper) alloy ribbons together. These ribbons are ordinarily 0.005 inches thick, 0.25 inch wide and of any desired length. The couple is insuated with mica and micarta paper to withstand a temperature of at least 150 degrees C. and substantial leads are brought out to the edge of the slot, and from the edge to the terminal board. The cold couple is located at the end of the advance wire leads and inside the measuring instrument.

With a difference of one degree C. between the temperatures of the hot and the cold couples, the difference in e.m.f. is approximately 40 micro-volts. This small voltage would force through the circuit only a very small current so that the measuring instrument must be somewhat different from the ordinary indicating meter type if a rugged, reliable device is to be obtained.

In Figs. 7 and 8 are shown two views of the instrument used, one as it is arranged for switchboard mounting and the other showing it mounted on the generator panel. It will be noted that it is arranged for mounting in a horizontal plane.

Mounted in this instrument case are the following parts:—

1 The cold couple.

2—In contact with the cold couple a small bulb type mercury thermometer by which the temperature of the cold couple is observed.

3—A dry cell supplying current through a resistance wire on which are two sliding contacts.

4—A graduated scale and two pointers which move with the contacts and which indicate the position of the two contacts.

5—A deflection needle of the galvanometer type.

6—A rheostat used for adjusting the current in the battery circuit to the proper value. The scheme of connections is shown in Fig. 9.

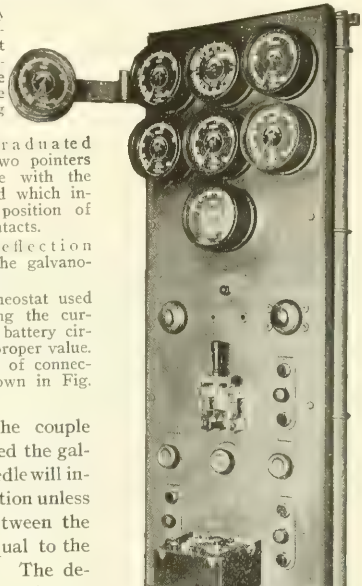

FIG. 8—SWITCHBOARD PANEL WITH POTENTIOMETER

When the couple button is closed the galvanometer needle will indicate a deflection unless the e.m.f. between the contacts is equal to the couple e.m.f. The deflection of the galvanometer needle will be in one or the other direction depending on whether the thermocouple e.m.f. is higher or lower. By changing the distance between contacts, using the galvanometer as a guide, the position in which the slide e.m.f. balances the thermocouple e.m.f. is easily located. In practice, the lower pointer is set at the position on the scale corresponding to the temperature of the cold couple and the upper pointer is moved until a balance is obtained as described. The actual temperature of the hot couple can then be read directly on the scale.

The temperature measured by the potentiometer is the difference in temperature between the hot couple and the cold couple. The indication on the slide wire scale, however, is the total temperature of the hot coil,

since the setting of the lower pointer on the scale at the temperature of the cold couple mechanically adds this temperature to the potentiometer or indicator measurement.

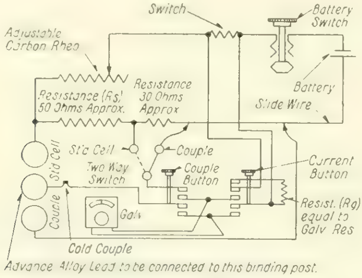

FIG. 9 DIAGRAM OF CONNECTIONS

Equipment Needed—A general scheme of connection is shown in Fig. 9. The entire equipment required for use will consist of the following:—

1—Thermocouples located in the machine, usually six to a machine.

2—A terminal board mounted on the machine near the main terminals for convenience.

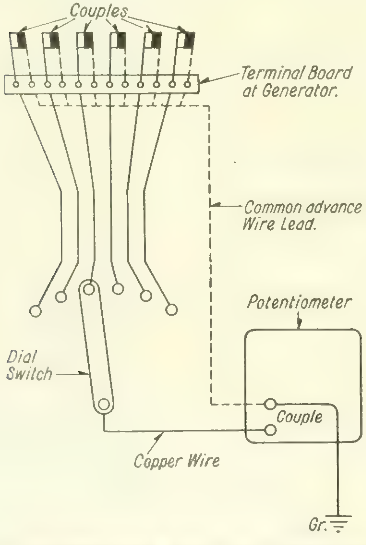

FIG. 10—CONNECTIONS USED WITH THERMOCOUPLES

3—A multi-conductor cable is used to connect the individual couples to the instrument. (In ordinary practice, individual copper wire leads are used to connect each individual couple to the instrument and a common advance alloy lead connects all the couples to the instrument. This side of the circuit is usually grounded in order that no voltage may be carried to the switchboard by failure of the armature coil insulation to the couple which would allow generator potential on the circuit. Also in order that any static disturbance may not affect the accuracy of the instrument.)

4—A dial switch, usually located on the switchboard near the indicator, used for switching each individual couple on which measurement is desired to the indicator.

5—The temperature indicator or potentiometer.

Deterioration of the couple is likely to take place if it is left in the circuit continuously and the couple button on the instrument is used for closing the circuit only when a reading is desired.

The dial switches from a number of machines may be interconnected and this makes it possible to read the temperatures from a number of machines at one point and with one instrument. This arrangement is shown in Fig. 11.

Either the exploring coil or thermocouple method, when properly installed, will give a satisfactory means of following the temperature conditions in large generators. The thermocouple method should give nearer the maximum measurable temperature, as it indicates

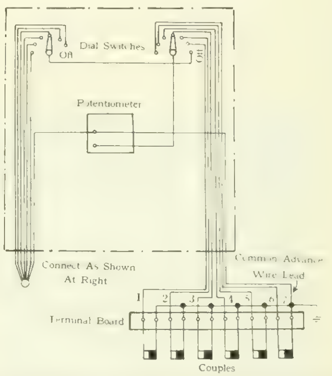

FIG. 11 DIAGRAMS OF CONNECTIONS FOR DIAL SWITCHES

It is possible to read the temperature from a number of machines at one point.

the temperature at a spot while the exploring coil gives the average temperature over its length. There is an advantage also in the thermocouple method in that it is self-contained and requires no external source of voltage and is fully as easy to operate as either of the exploring coil devices. The thermocouple device is a zero reading method; consequently the resistance of the leads does not affect the calibration. The fact that it does not employ an indicating instrument cannot be considered a handicap, as usually it is desired to read all the detectors, and this requires a certain amount of manipulation with either method.

Improved Industrial Lighting

Wm. T. Reace
Illuminating Engineer,
Commonwealth Edison Co.

DURING the late wartime period through which our country has so successfully passed, production became the cry of the hour, from the highest official of the nation down to the patriotic machinist in the shop. Improvement and modification of machinery, installation of more efficient shop practice, higher wages, these all were marshalled forth in the demand for an increased rate of production. Twenty-four hour day running time became common in a large number of the industrial institutions from coast to coast. This sudden pressure on these industrial establishments caused improvements in every line of their equipment and brought to the attention of many superintendents and owners that too little appreciated production assisting associate, artificial lighting. For years, it is true, artificial light has been used in factories and industrial establishments, but its value was not appreciated or even tested except in isolated cases. Now as a result of the sudden pressure caused by wartime emergencies, efficient lighting of all industrial plants is beginning to receive the fair consideration so long lacking but so rightly due.

The condition which seems to exist in the majority of present installations is that of spot lighting, thought to be economical because of the small wattage lamps used. This fantastic economy soon fades when production and various other shop costs are studied. There is a bigger problem than just the lighting of the spot where the tool is working. What of all those other places such as the aisle ways, dark corners, material piles etc. We find that the proper lighting of these plays a large part in the daily work of the shop which eventually shows on the profit or the loss sheet in the ledger. Although there are classes of machine work that need an individual movable light, the great majority of the plants may be lighted efficiently and satisfactorily by means of a properly designed overhead lighting system. The use of large lamps placed in large reflectors is desirable in order to provide a greater area for the secondary source of light. With such large units placed reasonably close together an average intensity over the entire shop of 8 to 16 foot-candles may be obtained, and from this we approximate daylight in a small way, for the same average intensity prevails on the aisleways as at the machine, tool, or work bench.

The installation of this high intensity over-head lighting shows immediate results in the four major branches of shop practice:—

1—Increased production.
2—Decreased spoilage.
3—Decreased number of accidents.
4—Improved supervision.

Increased production alone, that is, greater unit quantity per day, is certainly a strong argument, but when in addition this increase is accomplished without increase in labor cost, the real value and importance of artificial lighting begins to be felt. Through a long period of fixed habit has come the idea that productive work is accomplished only under daylight conditions, but now with the advent of really effective artificial illumination we find that this idea is unfounded. The cost of artificial illumination is small in comparison with labor, and the saving of one half to three-quarters of a minute each hour will more than offset this cost.

The spoilage pile is the undesirable feature of many plants and its reduction will show immediate results in increased profits. A great deal of this spoilage is due to mistakes by workmen, many of which may be traced directly to poor lighting. And it must be remembered that spoilage is not the loss of one man's time for some few seconds or minutes, but often nullifies literally hours of work by previous operations on the product. One spoiled casting or article may represent many hours loss in shop time.

FIG. 1—COMPARATIVE LIGHTING CONDITIONS
Before and after installing an efficient lighting system.

It is a widely known fact that the peak period of industrial accidents throughout the year occurs during the calendar months when there is the greatest use of artificial light. This leads to the conclusion that artificial lighting is inferior to daylight. But we can lower this peak by using lighting systems that more nearly approach daytime conditions. To do this it is necessary to provide an overhead system of high intensity. The resultant elimination of bright and dark spots will to a large extent, effect the elimination of the causes of

many accidents. The reduction of accidents means an increase of shop efficiency and a decrease of financial liability.

The problem of supervision is important and is one which can be simplified to a large degree by proper artificial lighting. When the shop is flooded with an even light of high intensity the foreman or superintendent is enabled to see his men from any part of the shop. Then again these cheerful conditions caused by good lighting will re-act on the workmen, causing a greater degree of efficiency and automatically eliminating slackness and inefficiency.

Another very important issue is that of maintenance. With individual lights, which are usually hung low, the workmen can reach them easily, can change lamps at will, they are easily struck and the general result is that, even a few weeks after a new installation is made, it will be found to be in deplorable condition. This condition is automatically eliminated when the lamps are of high intensity and are hung high. There will then be a smaller number of lamps and a regular schedule of maintenance can be enforced. Proper lighting with large lamps overhead is to be highly recommended, but the value and necessity of regular maintenance must not be overlooked.

Chemistry and Chemical Control in the Lamp Industry

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Engineering Department,
Westinghouse Lamp Company

This paper does not pretend to cover all the detailed work that involves chemistry in the lamp industry. Rather, it is a short outline on some of the problems which enter into lamp manufacture, and is meant to serve the purpose of pointing out the relation of the chemist and of chemical principles to an industry that might appear to have few things in common with chemistry.

NECESSARY as it is that we have electricity to operate the modern incandescent lamp, just as necessary is it that we utilize our knowledge of chemistry in the manufacture of that lamp. The finished product is an article which, to look at it in a superficial way, suggests the handiwork of a thoroughly trained mechanic only. However, although the mechanical construction, in whatever form it takes, is a point of vital importance, yet the lamp, from a useful life standpoint, would be a failure if it were not for the chemistry which has been applied in one way or another in its manufacture. This is chiefly due to the fact that it is a product whose manufacture requires exceedingly careful scientific chemical control. Very exacting conditions are required inside the lamp in order that it may perform its functions properly and for a reasonable length of time. To create and maintain these conditions is largely the work of the chemist.

THE FILAMENT

Probably the most important part of a lamp is the filament itself, since it is the actual source of light and when it fails the lamp is no longer useful. Except in certain cases where a very rugged lamp is required and where the old carbon still is used on this account, tungsten has become the universal filament material. There are two reasons for this. It has replaced the old familiar carbon and metallized carbon lamp, because it gives a very much higher candle-power for the same wattage and because it has the highest melting point of all the metals, a relatively high resistance and a low vapor pressure near its melting point. Owing to its high melting point, the process of obtaining the drawn filament, which in many of the smaller types of lamps is considerably finer than the human hair, involves difficult mechanical and chemical treatment.

SOURCE OF TUNGSTEN

The ores from which the greater part of the metallic tunsgten is obtained are the minerals Wolframite and Scheelite. The former is essentially a tungstate of iron and manganese, while the latter is a tungstate of calcium. In either case, after the ore has been concentrated, it is finely ground, mixed with sodium carbonate and heated to a state of fusion. This converts the tungsten into soluble sodium tungstate, which is later leached out of the fusion with water, leaving a large part of the impurities behind in an insoluble form. After filtering, the solution of sodium tungstate is decomposed with acid, which separates the tungsten as a yellow fluffy powder, known as tungstic acid. It is in this form that tungsten finds its way into the lamp industry.

PURIFICATION OF THE OXIDE

If crude tungstic oxide, as it is received, were reduced directly an impure metal would be obtained which could, under no circumstances, be drawn into wire. It must consequently be subjected to a rather elaborate chemical purification to eliminate the impurities. At all stages of this purification process, chemical analyses must be made to determine what impurities and to what extent these impurities are present. The crude tungstic oxide is first dissolved in a strong solution of ammonia and the resulting solution filtered away from such impurities as silica, iron and alumina. The clear filtrate is then evaporated down and pure white crystals of an ammonium tungstate obtained. These are carefully separated from the mother liquor,

dried and heated in a furnace to a high enough temperature to drive out the ammonia. This leaves a greenish yellow residue which is tungstic oxide, and should contain but very few impurities. At this point, a chemical analysis is always made to determine whether sufficient of the impurities have been removed. The next process consists in reducing this purified oxide to the pure metal. This is usually accomplished by heating the oxide in a current of pure hydrogen to 1000 degrees C. It may be accomplished by heating the oxide with a pure grade of carbon. A gray crystalline powder results, which is pure metallic tungsten. Again a control chemical analysis is necessary.

FORMATION OF THE "SLUG"

A small quantity of this metal is placed in a strong mold and subjected to an enormous pressure by means of a hydraulic press. This treatment presses the metal

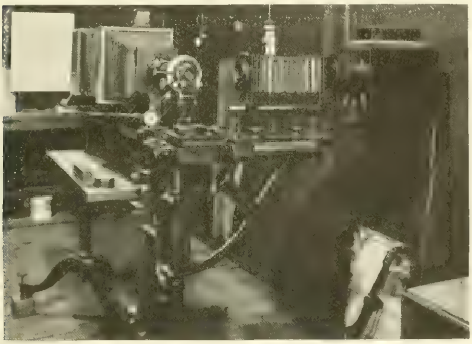

FIG. 1—PHOTOMICROGRAPHIC EQUIPMENT FOR MICROSCOPIC STUDY OF STRUCTURE OF MATERIALS
Westinghouse Lamp Company—Bloomfield, N. J.

into a fragile ingot about 8 inches long and 1/4 inch square. This must be handled very carefully and is transferred from the mold to a carbon slab upon which it is heated in a specially constructed hydrogen furnace. This treatment sinters the particles together to such an extent that it may be handled, although it is still very brittle. The ingot is now ready for the treating process which consists in heating it almost to its melting point in a non-oxidizing atmosphere by passing a very large electric current through it. This renders the ingot hard, compact and lustrous like a metal. It is now ready for the swaging and drawing processes, which are essentially mechanical.

CRYSTALLIZATION IN THE FILAMENT

If pure metallic tungsten alone were used as a filament material, crystals of tungsten would soon develop through the length of the wire when the lamp is first burned. After the development of these crystals, any jar which the filament might receive would cause the boundary planes of these crystals to slide upon one another. As a result, the cross-section of the wire at the point where this slipping had occurred would be reduced to such an extent that even the normal current would fuse the wire and a burnout would result. To overcome this tendency, a small amount of an inert oxide is usually added to the metal which serves two purposes; first, it tends to retard the rate of crystallization of the wire on burning and second, it acts as a binder between the boundary planes of the crystals, after crystallization has taken place. For this purpose, a solution of a thorium salt is added to the purified tungstic oxide. When the oxide is later heated, this salt is converted to the oxide. Since this oxide is not reduced by hydrogen, it remains as such in the reduced tungsten metal. The control of the amount of this material is very important. Enough must be present to perform its functions properly, while too great an amount results in serious troubles in the drawing process. Consequently, when the fired or purified oxide is subjected to analysis, a very careful determination of the thorium oxide content must be made.

DRAWING PROCESS

Although the drawing of tungsten wire is essentially mechanical in nature, chemistry plays an important role. Since metallic tungsten is only ductile when heated to a relatively high temperature, most of the drawing is done at a red heat or slightly higher. Like most other wire drawing processes, a lubricant is necessary. Graphite is the high temperature lubricant that is used. It is applied to the wire in a very fine state of division by passing the wire through a suspension of graphite in water. It is of considerable importance that this suspension be of the appropriate consistency and that it contain the proper percentage of solids in order that the right amount of graphite adhere to the wire. As a result, a chemical control must be maintained on the wire lubricant.

USE OF MOLYBDENUM

Although molybdenum has a lower melting point than tungsten and consequently cannot be used as a filament material, it finds its place in the lamp industry. In many types of lamps, where tungsten supports for the filament have been used, molybdenum supports are being extensively substituted. Its process of extraction, purification and drawing are very similar to those just described for tungsten. Certain impurities have a very serious effect upon the quality of molybdenum wire. A chemical analysis is always made of the oxide and metal in order that these impurities may be kept at a minimum.

GETTERS

From a chemical viewpoint, probably one of the most fascinating subjects is the work of substances called "getters". A "getter" is a substance put into the lamp bulb in order to give the lamp a longer life than it would have if the getter were not present. The getter may be either a solid or gas, depending on the type of lamp which is to be operated. All Mazda C lamps are gas filled, while the Mazda B type has a solid for a getter. As an illustration of the benefit derived from the use of getters, it may be stated that the

ordinary 40 watt 110 volt Mazda B lamp without getter will give a useful life, i.e., the time in hours before the lamp drops to 80 percent of its initial candle-power, of approximately 350 hours, while the same lamp with getter, will burn 1000 hours.

Lamps with tungsten filaments operate at a high temperature. While the lamps are burning, the evaporated tungsten metal lodges on the surface of the bulb, thus gradually cutting down the candle-power, due to blackening. To offset the blackening, two methods are in vogue. In the vacuum type of lamp, chemical substances are introduced which retard the blackening of the bulb and consequently extend its useful life. In the Mazda C or gas filled lamp, the pressure of the gas acts in opposition to the vapor pressure of the hot filament and the black deposit is formed very slowly indeed.

APPLICATION OF GETTERS

The methods of applying getters are various in form and often ingenious. One method is to mix up certain chemicals into a paste, using a suitable binding material. A very small amount of this paste is carefully put on the hooks that support the filament and allowed to set. The heat of the lamp, while burning, is sufficient to make the getter active. Getters are sometimes applied to the filament wire itself. In this case, a very thin paste is made and the wire drawn through the mixture contained in a specially constructed cup. On the initial lighting of the lamp, the getter is "flashed off", leaving the wire clean, while the chemicals are distributed throughout the inside of the bulb, the greater portion of it probably resting on the bulb surface. The thin getter paste may be sprayed on to the wire and glass parts in an appropriate way, or the same parts may actually be dipped into the getter. Depending on the nature of the substances used. Other getters are painted on to different lamp parts, while still others are placed in tiny glass tubes or vials. It may be appropriate to state here that the amount of getter put into the lamp by this means is very small indeed, the exact amount depending on the type of lamp.

The part the chemist plays in the application of getters, not gases, is in finding appropriate binders with which to hold the active material together till it is safely inside the lamp. Most of the plastics suitable for this purpose are organic in nature and most of them have hydrocarbons and water among their products of decomposition. Consequently, as far as possible, these products are removed during the course of manufacture. To find new and better binders and also new and better active materials for use as getters are problems of real importance.

GLASS

The glass parts of a lamp present problems which are very intricate in nature and which of all problems in lamp manufacture, are probably the least controlable. The physical properties of glass that are of chief concern are softening point, coefficient of expansion and electrical conduction. These properties are dependent to a large extent upon the chemical constituents of the glass and consequently can be changed at will by the chemist. Production demands require that easily workable glasses be utilized in the larger share of the work, in order to obtain speed in output and economy in fuel. Lead-alkali and lime-alkali glasses adapt themselves well for this purpose. The lead glasses are particularly desirable since they have a low softening point. They also anneal very readily and do not require exceptional care in working and sealing together the several parts of the lamp. For lamps that operate at low temperature, therefore, these glasses are well suited. However, for lamps of high wattages in which considerable heat is developed, glass with a much higher softening point is necessary or the glass parts may soften and subsequently collapse. Working conditions for hard glasses are much more limited than those of soft glasses, and their use entails great care.

Often it is necessary, although far from desirable, that glasses comparatively widely different in their physical properties and chemical make-up be used for different parts of the same lamp. So, for instance, in lamps of fairly high wattages, the glass cane that supports the filament may become so hot during operation that a hard glass for this purpose is absolutely indispensable. This demands that the supporting cane be sealed to a piece of glass tubing, having a coefficient of expansion very different from that of the cane. With the best of flame adjustments on automatic machines, a high shrinkage in this operation is likely to take place. Later, the stem so made must be sealed to the bulb, which is made of soft lead-soda glass, hence the necessity of using soft glass tubing for the seal just indicated above. It is cheaper to have a breakage at the former operation than later in sealing-in the stem to the bulb.

The problem of sealing metals to glass is also one of absorbing interest. Formerly, platinum was used to conduct the current into the lamp, because it, of all metals, had a coefficient of expansion about equal to that of soft glass, and therefore made a perfect seal. Now cheap substitutes made from alloys of nickel and steel are used for this purpose. Wires to support the filament are sealed into the glass cane. These are usually made from tungsten, molybdenum, nickel or other metals, depending on the coefficient of expansion of the kind of glass cane used. A necessary change in the cane due to electrolysis or softening may also necessitate a change in the kind of metal support.

PURIFICATION OF GASES

One of the most important things the chemical laboratory controls is the purification of the gases that are used for Mazda C lamps. Be it argon or nitrogen or a mixture of the two gases, in any case, no foreign gas must be present. As has been suggested, the slightest trace of water vapor is disastrous. Consequently, elaborate chemical means are used in order

first to purify the gases and then very careful control is utilized to see that the purity is maintained.

ACTION OF WATER VAPOR

It may be of interest to note what the probable behavior of water vapor is in the lamp and why it is so damaging. Its action is known as the "water cycle". At the high operating temperature of the tungsten filament, any water vapor coming into contact with the incandescent metal is decomposed into its constituents hydrogen and ozygen. The oxygen immediately unites with a part of the filament, forming tungstic oxide, which is volatilized and is thrown against the bulb. The free hydrogen in turn reduces the oxide so formed, leaving a particle of black tungsten powder in place of the less conspicuous and less light absorbing oxide, and water is again formed. So the cycle proceeds to the detriment of the filament and the candlepower of the lamp.

CONTROL OF OILS

If considerable care and control are not maintained, hydrocarbon gases will creep into the lamp from the oils used in the pumps which perform the exhaust operation. Heavy hydrocarbon oils are utilized for this purpose and the vapor pressure of such oils at the working temperatures must be practically nil. Castor oil, too, is used to insure a tight joint between the lamp and the rubber tube which holds it in place during the exhausting operation. As this joint becomes very hot, particular caution is exercised regarding the purity and the vapor pressure of this oil.

BASING CEMENTS

After the lamp has been exhausted and sealed off, a metal base must be cemented to the glass bulb. For this purpose, it is necessary to have a cement which will set quickly, will make a rigid connection between the glass and metal and which must be resistant to both moisture and reasonably high temperatures. Cements that are now used are made from formulas which are the results of years of work in the chemical laboratory. Although basing cements vary in composition, depending upon the type of lamp they are to be used upon and to the conditions to which the lamps are to be subjected, they usually contain various fillers with shellac, cut in either wood or denatured alcohol. All of these materials require a careful control, especially shellac, which is a gum imported chiefly from India and the South Sea Islands. It is a material that is very susceptible to adulteration and its adulterants are very difficult to detect. Its solubility and the viscosity of its solutions are factors which must be carefully controlled. During the war, owing to its source, the supply of shellac became uncertain. As a result, a large amount of chemical research has been carried out during the past year on substitutes for shellac and basing cements which do not require shellac as a binding material.

SOLDERS

The final operation in the mechanical construction of the lamp is to connect the lead-in wires to the base in such a way that good electrical contacts are made. This is accomplished by soldering them directly to the base. Before this can be done, the base must be cleaned from all oxide and grease at the point where the connection is to be made. For this purpose the solder used must contain a definite tin content in order that the melting point of the solder will be sufficiently low for efficient working. Owing to the shortage of tin during the war, a constant check on the tin content of the solder became necessary.

Mazda C Lamps for Motion Picture Projection

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About five years ago active work was begun on the problem of developing an incandescent source of light which could be used successfully in place of the carbon arc lamp for the projection of motion pictures. Early in the development it became evident that pictures could be projected with a Mazda lamp of the concentrated filament type; however, lamps of the usual voltage ranges were found to be difficult to make and unreliable because of the tendency to arc due to the extremely great concentration necessary. It also became evident that the success of a Mazda lamp for picture projection depended not entirely upon the wattage of the lamp but upon the amount of filament which could be placed within a given area, this area being approximately one-half inch square.

Various sizes and voltages of lamps were developed at different periods, but gradually the results have indicated that a 900 watt lamp, Fig. 1, rated at 30 volts 30 amperes, meets the requirements in a great many cases, and, therefore, this lamp has been adopted as the standard for motion picture projection. The use of this lamp is being demonstrated in order to bring it to the attention of theater owners, operators and managers so that they may learn how well the lamp meets the requirements. Application of the lamp has been retarded very largely by the fact that no satisfactory equipment was available for its use. Several lamphouse mechanisms have been developed for the Mazda lamp, but in many cases these have proven to be unreliable because of poor mechanical construction. There has also been a lack of equipment for the electrical control of the lamp. A Mazda lamp for motion picture projection is operated at extremely high filament temperature, therefore, the current supplied must

be accurately controlled. The compensators which have been used, heretofore, in theaters for the control of arc lamps do not have sufficiently accurate regulation for use with Mazda lamps, and it is necessary, therefore, to have either entirely new control equipment or to install an additional rheostat or reactance coil so that close regulation of the current is obtainable. The lack of these devices has limited the adoption of the Mazda lamp.

At the present time there have been developed and placed on the market several types of lamphouse equipment and electrical control devices which seem to meet all of the requirements of simplicity, ruggedness, reliability and ease of control. With this equipment available there will undoubtedly be a rapid increase in the use of Mazda lamps for projecting pictures.

ADVANTAGES OF PICTURE PROJECTION BY MAZDA LAMPS

The advantages which may be obtained by the use of Mazda lamps for picture projection may be outlined as follows:—

FIG. 1—900 WATT, 30 AMPERE, 30 VOLT MAZDA C LAMP
For motion picture projection.

1—Absolutely steady light, even on alternating current circuits of frequencies as low as 25 cycles per second.

The filament used in the Mazda lamp is a fairly heavy coiled tungsten wire which stores up enough heat to keep the temperature of the filament practically constant throughout the current cycle.

2—The absence of flicker permits the operator to use a three wing shutter which gives a high frequency cut-off so that there is no annoying flicker of the picture on the screen.

3—The lamp filament, when once focused at the proper point in the optical system, does not change in position and, therefore, more time may be given to watching the picture and producing the best possible results.

4—The light source being entirely enclosed in a glass bulb does not give off any gas vapors to injure the operator, and no dust is formed which tends to wear the mechanism of the machine and scratch the film.

5—The light on the screen does not vary from moment to moment as is the case with an arc lamp where the position of the arc is constantly changing with respect to the optical system. This gives a steadier and more pleasing picture to look at and one which produces little or no eye strain.

6—The color of the light is of a slightly yellowish tint which gives a more pleasing effect than the bluish white light of the arc.

PRACTICAL DEMONSTRATIONS

Recently, demonstrations were made in theaters in Boston and New Haven to show the possibility of using the 900 watt Mazda "C" lamp for regular theater operation. A new type of lamphouse was used in these tests. The equipment not only passed all the requirements of the Massachusetts Inspection Bureau, but gave results in picture projection which were beyond criticism.

It is recognized that the Mazda lamp is not designed for projecting the pictures in the largest theaters, but it is a desirable substitute for alternating-current arcs, and that it meets the requirements in a very large number of installations.

GENERAL FEATURES SIMPLEX EQUIPMENT

The lamphouse equipment, Fig. 2, has the following general features which are of particular interest, as they represent many advantages over most of the equipment which has heretofore been placed on the market:—

Practically all of the adjustment on the lamp may be made from the outside of the lamphouse. The lamp

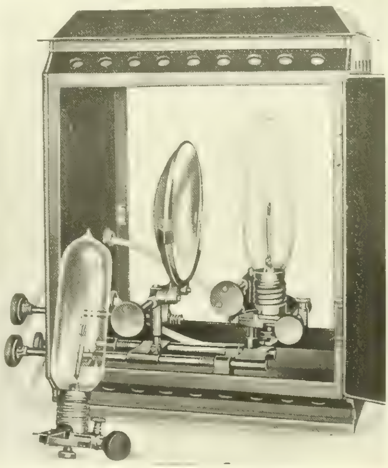

FIG. 2—SIMPLEX LAMP HOUSE
Showing extra holder and lamp.

is placed in a removable holder and an extra holder is provided so that new lamps may be installed without difficulty or loss of time.

Ample working space between the lamphouse and motion picture machine head is obtained by using plano-convex condensers of the usual type instead of a short focus prismatic condenser. The plano-convex condensers are suitable for the projection of stereopticon slides so that no mechanism is necessary for shifting from one set of condensers to another.

ADVANTAGES OF OUTSIDE ADJUSTMENT

The advantages of having handles for adjusting the lamp outside of the lamphouse are that the projectionist works comfortably, as the handles are not hot and adjustment can readily be made at any time in case of necessity. The mechanism is similar in its op-

eration to the mechanism of an arc lamp and, therefore, the operator can readily adapt himself to the new equipment. When adjusting the lamp, the lamphouse may be closed up so that the eyes of the projectionist are not blinded by the flare of light from the intensely hot filament. If adjustment is made with the lamphouse door open, as is necessary with most other types of lamphouses, the glare of the lamp prevents the operator from seeing the screen clearly for sometime afterwards, and he is therefore unable to accurately focus the picture on the screen.

One of the most accurate adjustments which needs to be made is the bringing of the reflected image from the mirror into its correct position between the spaces in the coils of the lamp filament. In Fig. 3A a filament is illustrated without the image from the mirror, and in Fig. 3B the same filament is shown with the image from the mirror properly adjusted between the coils. Unless the image is brought accurately to the correct position as indicated the effect on the screen is not what it should be, there being uneven illumination and also loss of light.

On the mechanism the mirror is provided with a long handle which reaches out through the back of the lamphouse. By means of this long handle the position

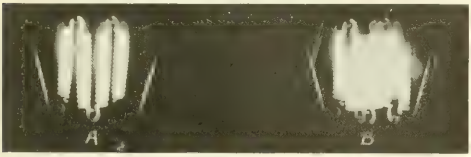

FIG. 3A—IMAGE OF FILAMENT WITHOUT REFLECTOR
FIG. 3B—IMAGE OF FILAMENT WITH REFLECTOR
Image spaced between coils.

of the mirror can be changed by a very slight amount, and thus the reflected image brought exactly to the desired position. The positioning of the mirror is one operation in the adjusting of a Mazda lamp for projection purposes with which the projectionist has not been familiar. With the arc lamp equipment he has been accustomed to adjusting the light source so that it gives the desired spot at the aperture plate. With the Mazda lamp it is necessary to get the lamp in correct position with respect to the condenser, and then bring the mirror into the correct position with respect to the lamp filament. This is an added operation, but it needs to be done only occasionally, because when the lamp and mirror are once correctly set they will, unless disturbed, remain in this position until the burnout of the lamp makes necessary the installation of a new lamp and consequently a new adjustment.

REPLACEMENT OF LAMP WHICH HAS FAILED IN SERVICE

As shown in Fig. 2, there are two lamp holders provided with the lamphouse equipment. These lamp holders provide for the lateral adjustment of the lamp so that the filament can be brought to very nearly the correct position before the holder is mounted on the adjusting mechanism. After a lamp has been installed the position is varied as may be necessary by the adjusting handles. The lamp and holder may then be removed and another one similarly adjusted. In case the lamp in service burns out, it is removed and the spare lamp with its holder installed. The only change which is liable to be necessary is a slight vertical adjustment due to differences in the light center lengths of the two lamps. In any case a fair light will be obtained for continuing the picture and the operator can make his final adjustment while the remaining part of the film is being run or after a change has been made to the other machine. The entire mechanism is strong and well made and fits inside a special lamphouse, which is of sufficient size so that a mirror of large diameter can be accommodated. The use of a large diameter mirror is advisable because the heating effect of the lamp is such that a small mirror will soon be destroyed. A large mirror will last longer than a small one, and it also will give a better image of the filament, so that there is a double advantage in its use. There is also room in the lamphouse to permit excellent ventilation, so that the lamp is always operated under conditions which are ideal for good performance.

AMPLE SPACE FOR EASY OPERATION OF MACHINE

The principal disadvantage in using a short focus prismatic condenser is that the lamphouse must be

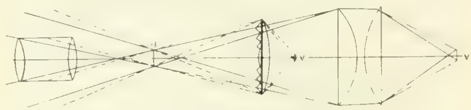

FIG. 4—DIAGRAM OF PLANOCONVEX AND PRISMATIC CONDENSER SYSTEMS
Showing spread of light beam.

brought very close to the machine head. With many types of machines this makes it difficult to reach the framing levers and focusing screw. With the equipment shown the lamphouse is in about the same position it would be if an arc lamp were used, so that the practical operation of the machine is not interfered with in any way. This ample working space makes it much easier to operate the machine and also reduces the danger of the projectionist burning his hands on the hot lamphouse.

CONDENSER SYSTEM

A diagram of the conditions which exist with the plano-convex and prismatic condenser system is shown in Fig. 4. With the plano-convex condenser the light source is placed at *a* while with the prismatic condenser the light source will be placed at *a′*. The rays of light from the plano-convex condenser pass through the aperture *b* and the greater portion of them are picked up by and passed through the objective lens *c*.

With the prismatic condenser, and the light source placed at *a′*, a very much larger portion of the light is lost because it does not pass through the objective lens *c*. The path of the rays of light of the prismatic condenser is shown by the dotted lines. With the pris-

matic condensers, part of this loss is compensated for because the light source shown at a' is much closer to the condenser than with the plano-convex condensers; thus, a somewhat larger angle of light is picked up. It is also evident that, where the prismatic condenser is used, it is much more important that an objective of large diameter be installed in order to pick up a greater portion of the diverging light rays. Owing to the fact that a lens tube, in a standard motion picture machine, is slightly less than two inches in diameter it is not possible to get the maximum effect from a lens having a greater diameter than this, though there will be some gain by the use of a 2½ inch lens.

Where the prismatic condenser is used it is necessary to provide a set of plano-convex condensers in order to project stereopticon slides. If a stereopticon slide is placed very near to the prismatic condenser the image of the condenser as well as the image of the slide will be shown upon the screen, thus giving a bad effect.

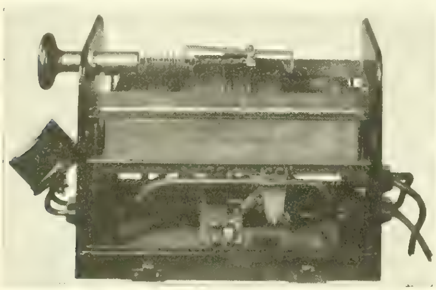

FIG. 5—MAZDA LAMP REGULATOR
With cover removed, showing moving coil and means for adjustment.

In ordering the lamphouse for a given projector the name and model number of the projector and the year in which it was manufactured should be given, so that the lamphouse which is sent out may be made up to fit the machine without the necessity of making any changes. By using this method, the lenses will be lined up correctly for the aperture plate. Where the installation of the equipment depends upon the accuracy with which the operator can center the condenser there is liable to be poor results. If the condenser is placed slightly out of line it will cause a very material loss in the illumination delivered to the screen, and there also will be an uneven distribution of light over the aperture plate, and consequently a badly projected picture.

ELECTRICAL CONTROL EQUIPMENT

In the development of transformers for use with Mazda C lamps for motion picture projection, it has been necessary to consider the accurate control of the current. The advantages of using constant current transformers have been appreciated and the main disadvantage has been that the lamps could not be made up so as to be rated absolutely at a fixed current. The latest type of transformer for this purpose embodies the constant current principle, but also includes means for regulating this current to the desired value. A view of the working parts of this transformer is shown in Fig. 5, while a view with the cover in place is shown in Fig. 6. The transformer is equipped with an ammeter and an adjusting knob, so that when the current is once adjusted to the value specified for the lamp, it will be maintained at this value under ordinary conditions, no matter if the primary voltage falls or rises. A transformer of this type has all the advantages which are usually found only on transformers of the constant potential type which are fitted with means for varying the secondary current. By the use of a special switching device a single transformer may be used to operate the lamps on two machines.

FIG. 6—MAZDA LAMP REGULATOR
With cover in place, showing ammeter and adjusting handle.

Dynamotors and Wind-Driven Generators

For Radiotelephony

R. G. Thompson

THE commercial development and manufacture of radiotelephone apparatus was one of the wonderful accomplishments of the electrical engineering profession of our country during the war. Not the least of the problems involved was the providing of a suitable source of power, as the requirement of portability and minimum weight and size precluded the use of the more usual forms of generators.

Three types of direct-current machines were needed in quantity lots to meet the power requirements of the various telephone sets, as follows:—

1—The 10-350 volt dynamotor, receiving power from a six cell storage battery on the low voltage end and developing 350 volts at 0.08 amperes on the high-voltage or generator end.

2—The 27.5-350 volt dynamotor, receiving power from a 16 cell storage battery on the low-voltage or motor end and developing 350 volts, 0.080 amperes on the high-voltage or generator end.

3—The 25-275 volt wind-driven generator developing 26 volts at 2.5 amperes and 285 volts at 0.080 amperes load at constant voltage from 3200 to 14 000 r.p.m.

All of these machines* are designed to furnish power for short range telephone sets with a working range of a few miles.

FIG. 1—RADIO DYNAMOTORS ASSEMBLED

This machine was furnished to both the Army and Navy for use on radio-telephone sets. The maximum range of a set using power from such a generator is from 10 to 20 miles, although several remarkable records have been made, the best being 198 miles. The construction is rugged and simple, and the brush holders are readily accessible.

The problem which confronted the engineer was to produce one standard design in which could be incorporated the special features and performance of any one of the three, this depending on the winding of the field and armature. Obviously this was necessary to get quantity production in minimum length of time, which was the outstanding difficulty. The result was one design of machine for all three requirements. As shown in Figs. 1 and 2, this is a single-armature, double-commutator, bipolar, ball-bearing, totally-enclosed direct-current machine, five inches in diameter and 8.5 inches long, weighing approximately 15 pounds.

The armature has two separate windings, insulated from each other, the low-voltage side being wound with a few turns per coil of large double cotton-covered enameled wire and the high-voltage side with a large number of turns per coil of small, single silk-covered enameled wire. After winding, the armature is banded with heavy cotton cord and given two dips in an impregnating varnish. A die cast aluminum end shield, as light as is consistent with strength, together with die cast aluminum brushholders, reduce the weight. The special type of ball bearing used, together with the through bolt and end bracket construction provide maximum ease in assembling or taking apart. The frame is machined from special steel pipe made for this purpose. The field poles are made from laminated steel and the field coils are wound with enamel wire.

GENERAL DESIGN OF MACHINE

The three principal considerations in the design of these machines are weight, efficiency and noise.

FIG. 2—DYNAMOTOR PARTS

The view shows the dynamotor parts ready for assembly. The die cast aluminum end brackets and brush holders, steel pipe frame and double commutator armature show the simplicity of construction and ease in assembly.

Weight—Since the dynamotors furnished the Signal Corps were for field service, and the generators were mounted on airplanes, minimum weight was essential. This reduction in weight was accomplished by using the smallest amount of iron and copper consistent with performance, and making the parts from aluminum wherever possible. The result was a machine weighing approximately 15 pounds.

Efficiency—As high efficiency as possible consistent with weight and noise limitations is necessary in all these machines. This is particularly true in the 10-350 volt dynamotor where the source of power is a six-cell storage battery which must be carried along with the rest of the telephone set. Low efficiency in the dynamotors means a larger battery, hence more weight to carry. This problem requires a careful analysis of the losses and a proper balance of the copper and iron losses to give maximum efficiency at the rated load. The efficiency is reduced owing to the ex-

*The radio apparatus which was used with these dynamotors and generators was developed and supplied by the Western Electric Company, and is described by Mr. H. M. Stoller in this issue. The writer gratefully acknowledges the assistance of Mr. Stoller in the preparation of this article.

acting noise requirements. The current required to start the dynamotor represents another important item as this also determines the size of the battery for the set. This current is reduced by use of a compound winding of the field.

Noise—Where generators are used to supply power to radio telephone sets, the minute fluctuations which are due to commutation etc. give rise to noise in the receiver circuit, which may seriously interfere with speech, if of sufficient volume. This noise can be reduced by care in the design of the machine. Some details of construction which help reduce this "electrical" noise are as follows:—

1—Large number of slots per pole in armature.
2—Armature slots skewed (see Fig. 2).
3—Large number of commutator bars.
4—Thin mica between commutator bars carefully undercut.
5—Brush pressure of from four to six lbs. per sq. in.
6—Large air-gap and beveled pole tips.
7—Highest grade soft graphite brushes.

All the above considerations are incorporated in the design in order to produce good commutation. The large number of slots per pole is necessary in order that commutation will occur when coil is at the point of best commutation. The large number of commutator bars reduces the number of turns per coil and hence the reactance voltage. Sine wave distribution of flux under the pole is obtained by beveling the pole tips. The ratio of the field ampere-turns required to overcome the reluctance of the teeth and air-gap to the armature ampere-turns per pole which produce flux distortion, (commonly known as the stability factor) should be high, as this is an important consideration affecting commutation.

In a given design, incorporating as far as possible all these desirable features, the amount of noise will not vary appreciably among individual machines, the quality and construction of the product being the same. Defects in workmanship on the generators that will increase the noise in the receiver circuit are rough commutators, high mica, poor seating of the brushes, incorrect brush position, low brush pressure, etc.

Since these machines are supplied with power from low-voltage circuits the first design employed metal-graphite brushes on the low-voltage end. These gave noise in the receiver circuit which was of such magnitude as to make their use impossible. Extensive experiments were then conducted to determine the brush which would give the quietest operation which resulted in the adoption of high grade, soft graphite brushes.

The greatest trouble with noise was experienced on the 27.5-350 volt dynamotor used on the submarine chasers. In these sets five stages of amplification are used thereby magnifying many times any noise due to the generator.

DYNAMOTORS

10-350 Volt Dynamotor—Most of the 10-350 volt dynamotors, the construction of which is shown in Figs. 1 and 2, were used by the Signal Corps for field sets to communicate both with airplanes and the units on the ground. The first of these machines were carried in a canvass bag hung over the shoulder by means of a wide strap. In the later sets this canvass bag was discarded and a water-proof aluminum box substituted.

Machines supplied the Signal Corps for inside use were mounted in a pressed steel frame which also served as a mounting for instruments and switches. A few machines similarly mounted were used by the Navy. The Signal Corps also used the 10-350 volt dynamotor for field telegraph sets. The output required for this service is 0.166 amperes at 300 volts. The 10 volt dynamotor was designed with a regulator to give 0.08 amperes at 350 volts and 0.166 amperes at 300 volts, thus making one machine meet both specifications.

The 27.5-350 Volt Dynamotors, Figs. 1, 2 and 3, were used on the submarine chasers and destroyers, two machines mounted as shown in Fig. 3 being used with each telephone set. One dynamotor only is operated

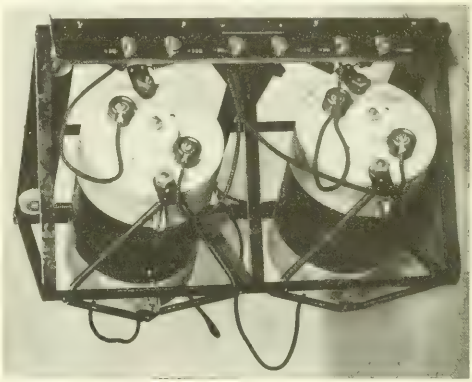

FIG. 3—DYNAMOTORS MOUNTED FOR USE ON SUBMARINE CHASERS

These dynamotors are hung in a spring suspension in order to damp out all noise which might be transmitted to the hull of the ship. When "listening" for submarines the only running piece of machinery on the ship is the dynamotor, and if means were not provided to prevent it, the noise of this dynamotor running is carried to the water through the ship and can be heard by the submarine. These machines are hung under the radio operators table and in the view shown here the camera was under the table looking up.

while the set is in use and the other is used as a spare. When the chaser is locating a submarine, the listening devices are used only when the vessel is not in motion and at this time the dynamotor is the only piece of machinery on the ship which is running. The sound of this running dynamotor transmitted through the hull of the ship to the water adjacent would confuse an observer attempting to pick up the noise of a submarine propeller by means of the sea tubes if no provision is made to prevent this. The spring suspension shown in Fig. 3 effectively damps out all sound of the running dynamotor.

Design—A dynamotor may be likened to a transformer with no reactance as the relations of current, turns and voltages are the same. In the transformer the winding is stationary with the flux varying; while in

the dynamotor the flux is stationary and the windings rotate. The ratio of generated voltages in the high and low-voltage armature windings is the direct ratio of the total number of series wires in each winding, since they both cut the same flux. This ratio is independent of all other factors.

The ratio of the terminal voltages depends on the ratio of armature series wires, the voltage drop in the

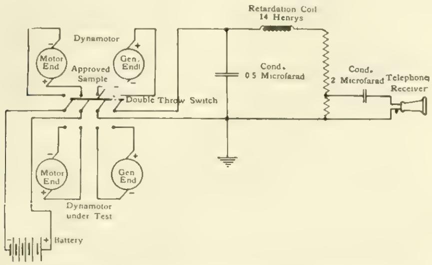

FIG. 4—CIRCUIT FOR NOISE TESTING OF DYNAMOTORS

No dynamotor is satisfactory unless it passes the noise test. The noise referred to is that obtained in the receiver of the set, and is usually due to brush contact and commutation. A similar testing circuit is used for the wind driven generators.

armature windings and the brushes, and the positions of the high and low-voltage brushes. On the low-voltage or motor end the voltage drop in the brushes and armature must be subtracted from the terminal voltage to get the generated voltage, while on the generator end they must be added. Hence this terminal voltage ratio varies with the load on the machine. The field and air-gap have no effect on this ratio except as they affect the losses.

Tests—The tests which are conducted on dynamotors before approval for shipment are given in the following order:—

1—The dynamotor is run for two hours at no load with the rated voltage supplied at the low-voltage end. This is done to grind in the brushes to 70 percent contact on the commutator face.

2—The voltage ratio is checked for no-load and full-load points.

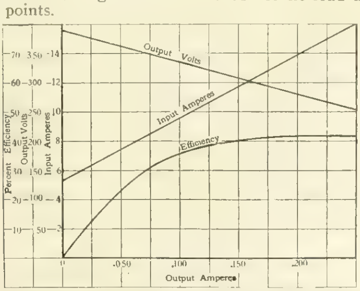

FIG. 5—PERFORMANCE OF DYNAMOTORS USED FOR WIRELESS TELEPHONY

3—The machine is given an insulation break down test of 1500 volts alternating-current between windings and between windings and ground.

4—A noise test is conducted with the circuit connected as shown in Fig. 4. With the circuit so connected the noise in the telephone receiver must be a steady clear commutation noise free from all scratching or rattling. An approved standard dynamotor is used as a basis for approval or rejection of the dynamotor tests. This noise standard test is supplemented by the trained judgment of the inspector.

Performance—Performance curves for the dynamotors furnished the Signal Corps are shown in Figs. 5 and 6.

WIND-DRIVEN GENERATORS

Both the Crocker Wheeler Company, and the Westinghouse Electric & Manufacturing Company, working under the direction of the Western Electric Company designed and manufactured wind-driven generators for radiotelephone sets used on the airplanes. The first machines were supplied to the Signal Corps through the Western Electric Company but later these were supplied to the Signal Corps direct. These machines were in use on the western front several weeks before the armistice was signed.

The wind-driven generator designed and manufactured by the Westinghouse Company, is shown in Figs. 7, 8, and 9. These machines are hung in a cradle on one of the landing struts of the plane and are driven by a small propeller blade. The propeller blade

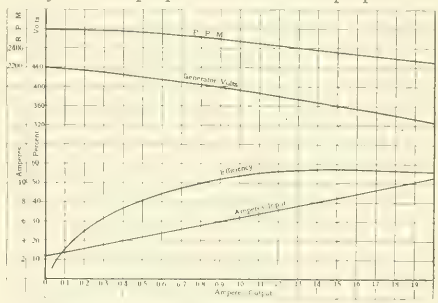

FIG. 6—PERFORMANCE OF DYNAMOTORS USED FOR WIRELESS TELEGRAPHY

A higher efficiency is obtained when the noise limitations are removed.

used for each type of plane is chosen so as to give a normal operating speed of approximately 6000 r.p.m. with a maximum variation of from 3500 to 12 000 r.p.m. The total weight is approximately 15 pounds. The machine is built from the same parts as the dynamotors, the difference being the double extended armature shaft, spun aluminum streamline front and tail casings, and the special type of die cast aluminum brushholders. The streamline casings are fitted tightly on to the finished brackets and make the generator weather proof. These are of such shape as to offer the least wind resistance.

The Signal Corps specification issued for this machine in January 1917 called for a 15 pound five inch diameter machine capable of the total load given above for constant voltage from 3500 to 14 000 r.p.m. This maximum speed requirement was later reduced to 12 000 r.p.m.

In addition to the special problems involved in the dynamotor design, this generator presented new design difficulties which are noted below.

Vibration—Excessive vibration on the plane necessitates extreme care in construction. Lock washers

or cotter pins are used on all screws and nuts. Two brushes, one set an angle with and one against the rotation, with brush pressures of four to six pounds per square inch, are used in each brush contact. All leads passing through the brackets or frame are brought through soft rubber bushings.

Centrifugal Stresses—The specifications called for a machine capable of operating at 14 000 r.p.m. mo-

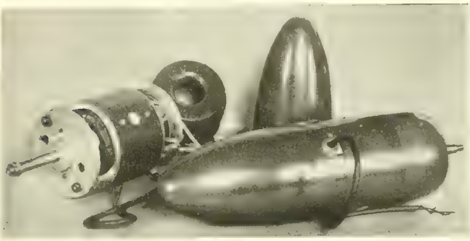

FIG. 7—WIND DRIVEN GENERATORS

Several thousand of these generators are in use on airplanes. The driving power is furnished by a small propeller. A radio telephone set supplied with power from one of these generators has a range of from 10 to 20 miles between planes.

mentarily without damage to the machine. With an armature 3.125 inches in diameter, 14 000 r.p.m. means a peripheral velocity of over two miles per minute and at this speed the problem of preventing the loosening of the armature end winding is quite difficult. This trouble was overcome by proper banding of the end winding with heavy cotton cord. A reinforced lead of extra flexible cable is used between the fine wire coil ends and the high-voltage commutator to prevent breaking at this point, due to centrifugal stresses, or expanding and contraction from heat and cold.

Balance—Dynamic balance of the armature is

FIG. 8—WIND DRIVEN GENERATOR PARTS

These parts are the same as those used for the dynamotors shown in Fig. 2, except for the double extended shaft, spun aluminum, front and tail casings $\frac{1}{32}$ inch thick, and special die cast brush holders.

quite a problem in such high-speed machines. The greatest possible symmetrical distribution of the armature end winding together with proper chain cord banding is necessary. Also, it is necessary that the armature be held in a vertical position during the dipping and baking process in order to insure symmetrical distribution of the impregnating compound inside the windings. By using these precautions and giving the armature a static balance by drilling the armature punchings on the heavy side a very satisfactory product is obtained.

Commutation presents a more serious problem here than in the dynamotors. In the dynamotors the motor and generator armature reactions subtract and the ratio of armature to field ampere-turns remains practically constant for a given load. The armature reactions in the double-current generators add and, for a constant-voltage variable-speed machine, the ratio of armature to field ampere-turns increases with the increase of speed, so that the worst commutation is obtained at high speed.

Voltage Regulation is the most difficult problem encountered in the design of a machine for this service. Whatever method is used must be first of all reliable and must require no adjustment or attention from the operator. At first a vibrating regulator machine was built employing a system of regulation which is now

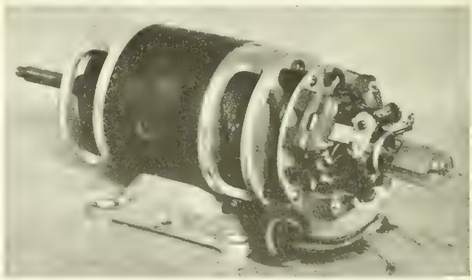

FIG. 9—VACUUM TUBE REGULATOR MOUNTING

The action of the vacuum tube makes possible this design, in which practically constant voltage is obtained through a speed range of from 2000 to 14 000 r.p.m. Soft sponge rubber pieces are used to mount the regulator on the machine, in order to protect it from vibration as much as possible.

extensively used in automobile lighting generators. In this system a resistance is cut into and out of the field circuit by means of a magnet actuated by a shunt coil connected across the brushes. The pulsations in the field flux due to the vibrating contacts produced additional noise in the telephone receiver circuits, and this scheme was abandoned for the system described below.

A very ingenious system which is better suited to this purpose than the vibrating regulator scheme was developed by Mr. H. M. Stoller. This method of regulation was adopted and used on all wind-driven generators for radiotelephone service. The regulation is accomplished by the use of a vacuum tube and a differential field which are connected in the circuit as shown in Fig. 10. Excitation is provided by two shunt coils. One of these is the main field winding and is built for operation on 22 volts, with a resistance of 15.5 ohms and a normal current of 1.2 amperes. It is excited from the low voltage commutator. This coil is wound in one section and mounted on one pole of the generator, filling the entire available winding space. The

other shunt coil, which is wound with very much finer wire and has a maximum resistance of 1430 ohms, is connected differentially to the main coil and is mounted on the other pole, also filling the entire winding space. This coil is excited from the 275 volt commutator and is in series with the other section of the above regulating device. The impedance of this section of the device varies widely throughout the speed range and the differential current varies from about 0.020 amperes at 3500 r.p.m. to 0.10 amperes maximum at 12 000 r.p.m.

Locating the main field winding on one pole and the differential field on the other pole reduces their mutual induction and renders more effective the damping winding which is necessary to prevent hunting. It is also simpler from a manufacturing standpoint.

The regulator tube is mounted on the commutator end bracket by means of sponge rubber cushions as shown in Fig. 9 and is enclosed and protected by the streamline tail casing.

THEORY OF OPERATION OF VACUUM TUBE REGULATOR GENERATOR

The voltage control is obtained by varying the field flux. This is done by the vacuum tube, the characteristics of which are shown in Fig. 11. In the diagram,

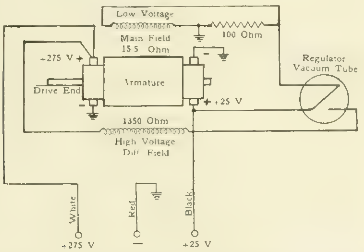

FIG. 10—SCHEMATIC DIAGRAM OF CONNECTIONS FOR WIND DRIVEN GENERATORS

Showing arrangement of generator and regulator circuits. The 100 ohm resistor is placed around the main field to prevent hunting.

Fig. 10, the main field carries the filament current and the differential field carries the plate current. The ampere-turns of the differential field oppose the ampere-turns of the main field. The vacuum tube acts like a valve. With a difference of potential of 275 volts, between the plate and the filament, and 0.95 amperes through the filament, no current passes from the plate to the filament. As the filament current increases the filament heats up and a current passes from the plate to the filament, varying with the filament current as shown in Fig. 11.

At 3500 r.p.m., the filament current is 1.2 amperes and excepting the current through the 100 ohm resistor, this passes through the main field. At this point the plate current, Fig. 11, which passes through the differential field is 0.02, amperes. Hence at 3500 r.p.m. the differential field is just beginning to act. The machine being a straight shunt machine, the terminal voltage rises as the speed increases and this increases the main field current. From Fig. 11 it is seen that a slight increase in filament current (main field) causes a large increase in plate (differential field) current. Hence as the machine speeds up the resultant excitation obtained by subtracting the differential field ampere-turns from the main field-ampere turns (hence the resultant field flux) is decreased in proportion, (this is true only for the unsaturated part of the magnetization curve). The result is practically constant voltage throughout the speed range, Fig. 12.

The differential field is designed so that with maximum permissible plate current (about 1.45 amperes) the differential field ampere-turns equal the shunt field ampere-turns. Hence at this point there would be no voltage generated and the machine automatically protects itself. In the present design the differential field develops about two-thirds the ampere-turns of the main field at maximum speed, due to armature reaction.

In Fig. 12 the curve "Percent Resultant Excitation" shows that the resultant field excitation does not decrease directly as the speed increases. The resultant

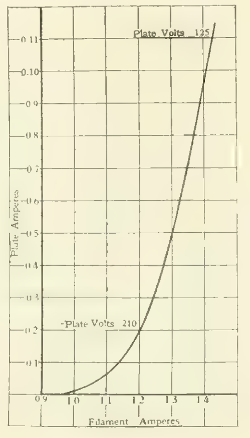

FIG. 11—CHARACTERISTICS OF VACUUM TUBE USED FOR REGULATION ON WIND DRIVEN GENERATOR

field excitation is practically constant above 10 000 r.p.m. and the differential action above this point is practically all due to the demagnetizing effect of the armature. The reduction in flux due to the armature is caused by the following:—

1—Distortion caused by cross magnetizing armature ampere-turns. This increases as the ratio of armature to field ampere-turns increases.

2—Demagnetization due to demagnetizing armature amperes. This action is constant throughout the speed range for a given load. This is quite important as the brushes on the low-voltage end are set one bar ahead of neutral.

3—Demagnetization due to short-circuit current under the brushes. This increases directly with the speed.

The brush position on both the high and low voltage ends is very important in determining the shape and value of the high-voltage regulation curve, since the magnetizing effects resulting are relatively great at high speeds. Four variations, all of which are due to armature magnetizing effects, can be obtained as follows:—

1—Keeping the high-voltage brushes on neutral and shifting the low-voltage brushes backward raises the high voltage and lowers the low voltage at high speeds.

2—Keeping the high-voltage brushes on neutral and shifting the low voltage-brushes forward lowers the high voltage and raises the low voltage at high speeds.

3—Keeping the low-voltage brushes on neutral and shifting the high-voltage brushes backward lowers the high voltage and raises the low voltage at high speeds.

4—Keeping the low-voltage brushes on neutral and shifting the high-voltage brushes forward raises the high voltage and lowers the low voltage at high speeds.

The operation of the first machines built was unstable because of hunting. This name was applied to a periodic fluctuation in voltage of about six cycles per second. The tendency to hunt is due to the fact that if pulsating power is applied to the filament circuit of the regulator tube, the pulsation of the temperature lags behind on account of the heat capacity of the filament. This unstable condition was produced by any sudden change in speed or load. It was found that this phenomenon was minimized by exhausting the vacuum tubes properly. It was also found that each of the

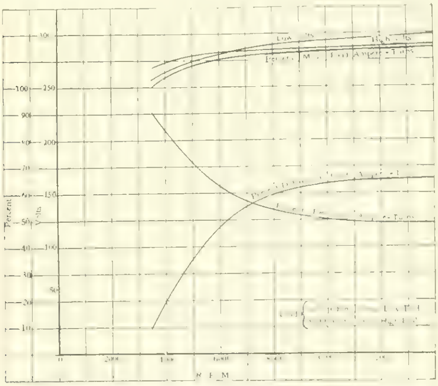

FIG. 12—CHARACTERISTICS OF WIND DRIVEN GENERATOR

With differential field winding and vacuum tube regulator. The ordinates for the low-voltage curve are one-tenth the scale.

following means checked the tendency to hunt and that by employing all of them hunting was completely suppressed.

1—A shunt resistance across the main field.

2—Connection of regulator filament at the positive rather than at the negative end of the field.

3—A short-circuiting damper of heavy copper strap around the main field pole rather than both poles.

The latter two are the most important. By proper design of the generator the 100 ohms shunt can be omitted.

The filament of the regulator tube normally operates at a high temperature, and melts quickly, opening the field of the generator, in case of excess voltage due to any cause whatever. Thus the regulator filament acts as a fuse and protects the generator and radio set from overvoltage.

Tests—Special tests are necessary to insure satisfactory operation of these generators after installation on the plane. These are given in the following order:—

1—Each machine is given an insulation breakdown test of 1500 volts alternating-current between windings and between windings and ground.

2—Each machine is run one-half hour at 8000 r.p.m. at full load and then given an overspeed test at 12000 r.p.m. for one minute.

3—The brushes are then set to give the performance specified and the above tests repeated four times.

4—The final test consists of a cold check on the performance of the machine throughout the speed range.

5—Noise requirements are checked by comparison with a machine used as a standard (Fig. 4) supplemented by the trained judgment of the inspector.

Throughout these tests a telephone receiver in series with 1000 ohms and a one microfarad condenser is connected in the circuit and if a failure (such as an open circuit or short-circuit) occurs in the machine, its presence is made known by excessive noise in the receiver.

A short-circuited or open-circuited armature coil, even though it does not affect the voltage readings, will produce a very pronounced click in the receiver which is readily recognized by an experienced observer. Sparking at the commutator, insufficient seating of the brushes, rough commutator, etc., each produces its characteristic noise. With experience, an observer is able to separate the individual causes of noise and criticise any defects in the generator under test. The voltage characteristics of the generator are shown in Fig. 12.

OTHER TYPES OF RADIO DYNAMOTORS AND GENERATORS

In addition to the three standard machines described above a number of types have been made in small quantities. Most of these special designs have been built from the mechanical parts of the standard machine, except for the windings and special mountings.

The latest types of wind-driven generators, which have been developed for the Signal Corps, employ a constant speed fan, in order to dispense with the regulating device and the undesirable features inherent in a variable-speed machine. The generator is similar to the standard generator, except for the armature and field windings and special field poles. Variations in temperature within reasonable limits affect the machine very little as the magnetic circuit is heavily saturated.

These special machines are wound for voltages of 500, 750, and 1500, and are all self excited. In the 1500 volt generator each half of the armature is wound for 750 volts and the two commutators are connected in series. A 20 volt exciter is mounted on the rear end bracket. One special dynamotor, rated at 0.4 amperes at 400 volts is used by the navy for wireless telephony sets with a range of about 50 miles.

CONCLUSION

The solution of the design and manufacturing problems involved as described forms an interesting chapter in the history of the war, in that it illustrates the way in which the organization of a peace-time industry was applied to the production of a war-time essential. It is only within the scope of this paper to tell how this war time need was met by the design of a machine which would meet the various specifications and yet be suitable for quantity production in minimum time.

Development of Airplane Radiotelephone Set

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SHORT range radiotelephone sets were used extensively by both the Army and Navy during the last few months of the war.* These were made in a variety of different forms, including airplane and seaplane sets, ground sets, and sets for submarine chasers and destroyers. This article will describe one of these radiotelephone equipments, which is coded by the Signal Corps as the SCR-68 set. It was designed for airplane use, and its development involved many peculiar difficulties involving noise, vibration, shocks on landing, etc.

ARRANGEMENT OF EQUIPMENT

A view of the various parts of the equipment is shown in Fig. 1. A wind-driven generator, located on one of the struts of the landing gear, furnishes the power supply, which is led through a filter box containing an inductance and condensers for smoothing out the commutator ripples. The power is then led to the radio set proper in which the transmitting and receiving circuit equipment is assembled. The two plugs shown at the lower right hand side of the set lead to an interphone box, by means of which the radio operator may also talk with the pilot, using an ordinary telephone circuit. Usually the antenna consists of two small braided copper wires trailed from the wing tips. When flying alone so that there is no danger of entanglement, there is some advantage in using a single wire about 300 feet long with a two pound lead weight shaped like a fish attached to the end. Recent developments have made it possible to employ much shorter antennæ, which however require the use of shorter wave lengths. Fig. 2 shows a pilot and observer seated in an airplane which is fitted with this equipment. The helmet which contains the receivers is designed to fit the operator's head snugly in order to exclude wind noises. It was found necessary to have the helmet cover completely the bony parts of the head so as to prevent transmission of noise to the ear drums.

FIG. 1—AIRPLANE RADIOTELEPHONE EQUIPMENT

FIG. 2—PILOT AND OBSERVER WITH RADIO EQUIPMENT

RADIO SET

The outside and inside appearance of the radio set proper, which contains the transmitting and receiving tubes with their auxiliary circuit equipment, is shown in Figs. 3 and 4. A schematic diagram of the transmitting circuit, is shown in Fig. 5, which consists of two three-element vacuum tubes connected to an input transformer operated by a microphone telephone transmitter. The oscillator tube feeds an oscillation circuit in which the inductance is supplied by the antenna coil and part of the capacity by the antenna.

When the transmitter is actuated there is a certain normal value of voltage impressed upon the grid of the modulator tube, this value being adjusted until the plate current of the modulator is about the same as that of the oscillator. The characteristic curve of the

*The success of the airplane radiotelephone was announced in General Squier's report on "Aeronautics in the United States" presented at the January meeting of the A.I.E.E. The development and quantity production of this radioequipment within the limited time available has been classed as one of the achievements of the war. The work was undertaken at the direction of the Radio Development Section of the Signal Corps. The manufacture of the radio sets was assigned to the Western Electric Co., while the associated power equipment was made by the Westinghouse Electric & Mfg. Co. and the Crocker-Wheeler Co. The paper on "Radio Telephony" by Messrs. Craft and Colpitts, presented to the A.I.E.E. in February 1919, gives a summary of the research and development work of the American Telephone & Telegraph Co. and the Western Electric Co. It describes the demonstrations in transatlantic telephony made in 1915 and 1916, the subsequent use of radiotelephony between ships, and finally the quantity production of short range radiotelephone sets used by the Army and Navy in the war.

transmitting tube, Fig. 7, shows that as the grid becomes more negative, the plate current decreases at constant plate voltage, and with positive grid voltage it increases. This may be described by saying that the resistance of the plate circuit may be varied by varying the grid voltage. An inspection of the curve shows that this variation may be from a very high value to a small value for positive grid voltages. The transmitter voltage acts upon the grid of the modulator and causes the resistance of the plate circuit to vary through a wide range in accordance with the speech voltage. Since this circuit shunts the plate circuit of the oscillator tube (at audio but not at radio frequencies) the oscillator will be robbed of current or have additional plate current forced through it in accordance with the speech voltage. It is seen that this system is essentially a constant current system, since it is supplied through a low frequency choke coil, the function of which is to maintain practically constant

FIG. 3—SIGNAL CORPS SCR-68 RADIO TELEPHONE SET

current to the two tubes no matter how the plate currents may vary individually.

A complete schematic circuit of the set is given in Fig. 6. A multibladed switch, the handle of which is shown in Fig. 3, is used to make the necessary circuit changes between transmitting and receiving. As all adjustments may be made on the ground, this switching is the only manipulation required by the operator. The handle is designed for use with a heavily gloved hand. The receiving circuit consists of a detecting tube and two stages of amplification, being similar in principle to the receiving circuits in common use in telegraph sets. The characteristics of the receiving tube are shown in Fig. 8. The battery which furnishes plate current for the receiving tubes is mounted in the radio set and is made up in two 22.5 volt units each weighing a little over a pound. These units are composed of 15 small dry cells. The complete transmitting and receiving set is approximately 17 by 10 by 7 inches [illegible] pounds.

GENERATOR

The wind-driven generator furnishes plate voltage at from 275 to 300 volts and filament voltage at from 25 to 30 volts. The development of the generator proved to be a considerable problem in itself, as it was necessary to secure constant voltage over a range of speed from 4000 to 12 000 r.p.m., which corresponds to an airplane speed range up to 160 miles per hour. In addition to all of the ordinary requirements for power equipment there was the additional requirement of furnishing current free from commutator ripples and brush noise. The regulation was accomplished by means of a vacuum tube regulator while the noise was suppressed by means of special generator design and the use of a filter. Fig. 9 shows its appearance with the "stream line" tail removed.

GENERATOR PROPELLER

The generator propeller is built of birch mounted on an aluminum hub, and has a weight of about 14 ounces. It is essentially an air screw similar to the engine propeller, except that it runs with a small slip below synchronous speed* while the engine propeller

FIG. 4—INSIDE VIEW OF SET

runs somewhat above synchronous speed. Fig. 10 shows the characteristic curves of a propeller, having a pitch of 0.80. These were taken in a wind tunnel at the Washington Navy Yard. The no load speed is exactly proportional to the first power of the wind velocity as seen by comparing the curves for 50 and 60 miles per hour. The point of maximum power is roughly proportional to the cube of the wind velocity. This might be expected from the fundamental consideration that the kinetic energy of a cubic foot of air is proportional to the square of the velocity while the number of cubic feet striking the propeller per second is proportional to the first power of the velocity.

As the wind tunnel was not equipped to give higher wind velocities, no information was obtained as to the velocity range over which the above stated laws would hold. It was not convenient to take such measurements on an airplane, but our experience gives us reason to believe that the laws hold over the entire range up to the maximum velocity of which the airplane was capable.

*The synchronous speed may be defined as the speed at which no power would be taken from or delivered to the air current.

The centrifugal stresses in the propeller blades were considerable. A testing machine was constructed which showed that propellers made with properly selected wood could be safely operated at 12 000 r.p.m. It was later found possible to employ propellers of somewhat greater pitch thus reducing the normal speed.

PERFORMANCE

The complete radio equipment is designed for short range communication over distances of a few miles only, although it has been used up to distances of 18

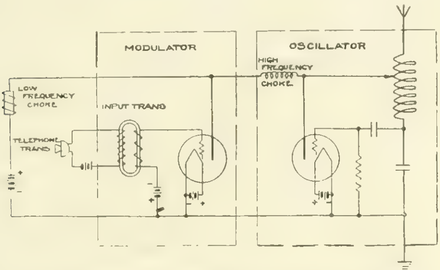

FIG 5 SCHEMATIC DIAGRAM OF MODULATION SYSTEM

miles under very favorable conditions. Adjustments are provided which permit the use of wave lengths from 200 to 500 meters. The power output to the antenna at a wave length of 400 meters with a single wire antenna 300 feet long is about 0.75 watt. It is interesting to note that out of this 0.75 watt radiated, the power received by another set three miles away would be of the order of 10^{-8} watts.

Ordinarily there is no trouble from atmospheric static owing to the use of such short wave lengths. However, the ignition system of the airplane engine sets up electrostatic disturbances which produce a very sharp crackling in the receiver unless the ignition wir-

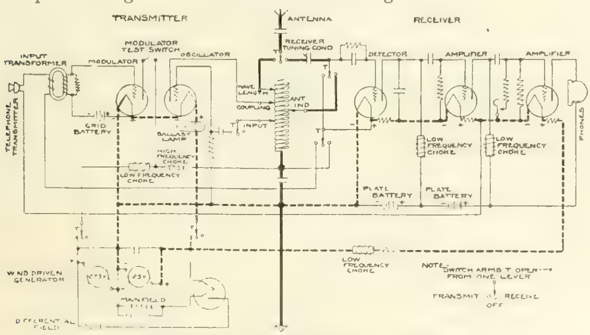

FIG 6—SCHEMATIC CIRCUIT DIAGRAM—RADIO TELEPHONE TRANSMITTING AND RECEIVING SET

ing is properly shielded by a grounded metal sleeving. There is also a certain amount of noise due to the generator commutation ripples. When transmitting, the ratio of the amplitude of these disturbances to the amplitude of the transmitted signal is sufficiently low, but as the received signal is extremely minute, a very small commutator ripple will be comparable to the strength of the voice current. For this reason a choke coil is employed in the receiver filament circuit which suppresses these disturbances. In addition, the two condensers in Fig. 6 are connected across the generator armature leads and assist by partially absorbing the commutator ripples. These condensers together with the choke coil are mounted separately in the filter box.

TRIAL FLIGHT

The writer has a very distinct recollection of the first flight in which he talked by radiotelephone. It

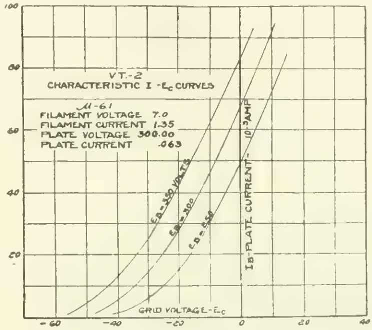

FIG. 7—CHARACTERISTICS OF TRANSMITTING TUBE

was on April 12, 1918, at Langley Aviation Field, Virginia. Previous flights had been made with specially built models of the radio set but this was one of the first trials of a tool-made set representative of quantity production. The purpose of the flight was to observe the operation of the set and note any defects.

We climbed into the plane, put on the receiver helmets, adjusted the breast transmitters and strapped ourselves in. While the engine was being given a preliminary spin on the ground to warm it up, we talked

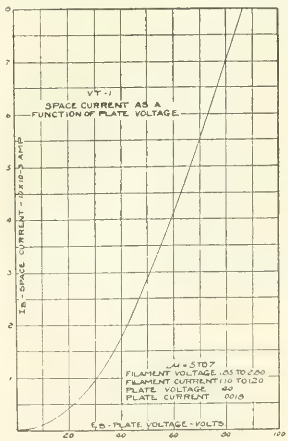

FIG. 8—CHARACTERISTICS OF RECEIVING TUBE

over the interphone to make sure that it was in working order. We then went down to the end of the aviation field and made a half circle back, climbing gradually. The high pitched note due to the revolutions of the wind-driven generator could be heard above the low pitch of the engine propeller, and by looking through

the transparent windows at the filaments of the tubes in the set, it was evident that the power supply was working satisfactorily. The pilot then interphoned to let out the antenna. After making the required number of turns to let out 300 feet, the switch of the radio set was placed in the transmit position.

One of the difficult things is to know what to say on occasions of this sort. The only requirement is to talk, so that all sorts of subjects were discussed. I described the river, which was stretched out about 3000 feet below and the white oyster shell roads which are the bane of automobilists along the Virginian coast. Mr. A. A. Oswald, also of the engineering department, of the Western Electric Co., had in the meantime gone up in another plane, and was listening. After talking for a few minutes I said, "Good-by, Oswald, come in now", and threw over to the receiver position. I could hear the "spit", "spit" of the magneto, for we had not as yet found out how to shield the wiring, and I could also hear the commutator noise of the generator. A moment later I heard, "Hello, Stoller" coming into the receiver, and I must say that in spite of the fact that I had used these sets on the ground and was expecting it, the sudden sound of a human voice which I clearly recognized gave me quite a start. It happened that we were not over two miles apart at the moment and with the antennæ in a favorable position, so that the words were heard quite loudly. Mr. Oswald said that he had heard me distinctly, and then told me to have my pilot turn the plane down toward Old Point Comfort and he would go up the James River. We would then report to each other where we were from time to time and thus determine the range* of the set between airplanes.

FIG. 9—WIND DRIVEN GENERATOR

We thus talked back and forth for about three-quarters of an hour. The maximum range attained at that time was eighteen miles for a one-way conversation, for it was found on switching back again that the speech had become too faint to be distinguished. We then turned around to go back to the aviation field. We were now flying at a height of about 4000 feet, at a speed of about 80 miles an hour. Suddenly the pilot shut off the engine tipping the plane down at an angle of about 45 degrees, and I could then hear very distinctly the singing note of the generator propeller. The pilot then turned on the engine, keeping the nose of the plane tilted downward, when the pitch of the wind-driven generator could be heard rising, indicating that we were moving at a very high speed for this type airplane, probably well over a hundred miles an hour. The filaments in the set could be seen at their normal brilliancy, which showed that the generator was regulating properly at this high speed. We were now approaching the aviation field, and the antenna was reeled in. We proceeded until we were directly over the hangars and then the pilot made a spiral for the last 2000 feet, and glided down very smoothly in front of the hangars. We found out that our conversation had been picked up during the first half hour of our trip by the ground set located in one of the hangars.

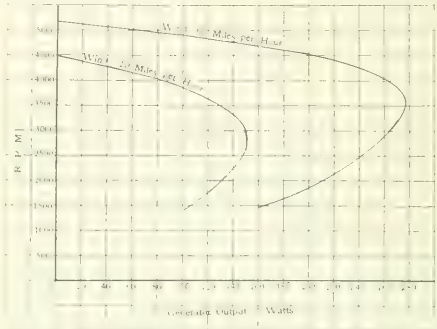

FIG. 10—CHARACTERISTIC CURVES OF 15 INCH PROPELLER
Tested with 300 watt generator.

*The range is about 50 percent greater between planes than between a plane and ground for a two-way conversation.

Increasing the Load with Portable Lamps

Arthur E. Frankenberg
Supervisor, Lamp Section,
Electric Shop,
Commonwealth Edison Company

If FIVE YEARS ago someone had predicted that more than half a million dollars worth of portable lamps would be sold in a year in one retail store, he would probably have been regarded in T. R.'s historic phrase, as an "out-patient of Bedlam." But, nevertheless, we are living in such an age and that and more is being done today in the Electric Shops of the Commonwealth Edison Company, Chicago. Large lamp displays in sales rooms of electric light companies are becoming more popular each year because they are realizing that the aggregate sale of portable lamps means a large added consumption of electric current each year.

Some people remark that in selling a lamp a customer often discontinues the use of the permanent fixture and, therefore, there is no added consumption. But we cannot agree with such a statement, because although a customer may discontinue the use of the fixture, yet we have found that they have replaced it with the use of two or three lamps, thereby adding so much to the decorative value of the room and generally increasing the consumption about three fold. This increased consumption means very little to the pocket book of the consumer, who has obtained the correct lighting for which he has been looking. As he sits back in his easy chair and comfortably reads the evening paper, he blesses the electric light company for the ever-ready service which he has at his command.

The Commonwealth Edison Company has provided a floor space of approximately 10 000 square feet for the special display of portable lamps, shades and fixtures, and as time rolls on no doubt a greater space will be needed to handle the ever-increasing sales. This display is generally recognized throughout the trade as being the most complete and well arranged display in the country, showing at all times approximately 150 floor lamps, 250 table lamps, 75 fixtures, 100 desk and boudoir lamps, etc. We have an average attendance of five thousand people per day, but in spite of this large attendance, if it were possible to get authoritative data as to the number of people in the city that are not using a single elecric table lamp in their homes, the figures would doubtless be surprising.

What is the reason for this? The majority of customers (we will estimate them at 80 percent) of an electric lighting company are people in moderate circumstances, in many cases with a fair sized family, who, have to count upon practically all of their earnings to meet their living expenses each week. At the end of the week, after paying the grocer, milkman, butcher etc., they find they have only a dollar or two remaining that has not been eaten up in the high cost of living, and which they might invest in some household necessity if they could find something that was attractive but inexpensive.

Portable lamps have in the past been generally looked upon as an expensive luxury, ranging in price from $25 upwards. Mr. E. A. Edkins, general manager of our Electric Shops, realized this and also that there would be a large demand for a low priced but attractive lamp, and he was instrumental in gathering together a number of sales managers representing various central stations who agreed to underwrite the output of certain products. In co-operation with an eastern lamp manufacturer, they designed a portable lamp which, if manufactured in large quantities, could be sold at a price that would place one in every home. The result was the experimental production in 1918 of a two light portable lamp with a 16 inch Shade for $6.75, and this year the underwriters have ordered 30 000 lamps of a new and much more attractive design that will retail at $9.75. This lamp, if manufactured in small quantities, would have to be sold for about $18.

The Commonwealth Edison Company has not only increased their sales in the Electric Shops by thousands of these moderate priced lamps, but has also helped educate the Chicago public in the value of correct and decorative lighting, and also increased the consumption of its principal product—electricity. The portable lamp of today is, therefore, looked upon as an essential in the home and, in fact, one of the very first things the housewife does in furnishing the home is to figure on laying aside a stipulated sum of money for electric lamp furnishings.

During the year 1918 we added approximately 5000 kw of rated capacity to the lines through the sale of portable lamps and expect to double that figure during 1919. The same results are possible with other utility companies. Our company entered the retail electrical merchandising business in a modest way but, with correct buying policies and progressive sales methods, we have been able to develop our business into one of the largest of its kind in the world. Last year we conducted a washing machine campaign and with each sale we gave as a premium a library table lamp and an electric iron. The total consumption of these articles is approximately 800 watts, and we sold approximately 1000 of these machines during the last three months of 1918. This year we are aiming to sell 3000 washing machines, giving with each sale a mahogany finished floor lamp and silk shade which involves the sale of $450 000 worth of merchandise with a total wattage of 810 000.

When the Electric Shop was opened, many people

referred to its chances for success in a pessimistic manner. To occupy so large a space for the sole display of electrical merchandise was an undertaking that had never been attempted before, and many people predicted failure. That we have more than doubled the space of the original Electric Shop in the past two years is, evidence of its success. During the year 1918 the Electric Shops sold over \$1 000 000 worth of electrical merchandise, of which approximately \$400 000 was portable lamps and at a handsome net profit. That was at a time when many other concerns would have considered it a good year if they had achieved an even break.

Essentials of Transformer Practice-XXII

Phase Transformation with Autotransformers

E. G. Reed

WITH two-winding transformers the Scott connection is the most desirable arrangement for securing a three-phase to two-phase transformation, and with autotransformers the connection still retains its advantages. There are three cases to be considered when analyzing this transformation for autotransformers.

1—WHEN THE TWO-PHASE VOLTAGE IS GREATER THAN 86.6 PERCENT OF THE THREE-PHASE VOLTAGE

Fig. 1 shows two autotransformers, connected for this transformation. A condition of balanced load is assumed in order to simplify the problem. In determining the k.v.a. rating of the autotransformers, it is necessary to know the currents in the various parts of the windings. The currents whose values are not obvious, are I_{fd} and I_{bf}. From Fig. 1,—

$$I_{fd} = I_{dD} + I_{aA}$$

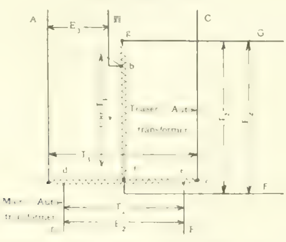

FIG. 1—CONNECTIONS FOR THE CASE WHERE THE TWO-PHASE VOLTAGE IS GREATER THAN 86.6 PERCENT OF THE THREE-PHASE VOLTAGE

The phase relations of these currents are shown in Fig. 2, and the numerical value,—

[illegible]

Since the cosine of 30 degrees is 0.866 and the sine of 30 degrees is 0.5.

[illegible]

The next step is to secure an expression for I_{aA} in terms of I_{dD}.

[illegible]

and

$I_{dD} =$ [illegible]

Combining these two equations gives,—

[illegible]

Substituting this value of I_{aA} in equation (1), gives,—

$$I_{fd} = \left(\frac{E_2}{E_1} - 1 + j\,0.577\frac{E_2}{E_1}\right) I_{dD}$$

$$= \sqrt{\left(\frac{E_2}{E_1} - 1\right)^2 + 0.333\left(\frac{E_2}{E_1}\right)^2}\; I_{dD} \ldots\ldots\ldots\ldots (3)$$

The current in the remaining part of the main autotransformer is aA, whose value, in terms of I_{dD}, is given in equation (2). The sum of the products of the voltage and current in the two parts of the main autotransformer winding gives its k.v.a. rating as follows:—

K. v. a. of main auto =

$$\left[\sqrt{\left(\frac{E_2}{E_1} - 1\right)^2 + 0.333\left(\frac{E_2}{E_1}\right)^2}\; E_1 + 1.151\frac{E_2}{E_1}\,(E_1 - E_2)\right] I_{dD} \quad (4)$$

The total k.v.a. transformed =

$$2\,E_1\,I_{dD} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

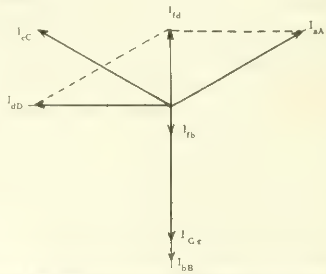

FIG. 2—PHASE RELATIONS FOR THE CONNECTIONS SHOWN IN FIG. 1

Then,—

$$\frac{K.\,v.\,a.\ of\ main\ auto}{K.\,v.\,a.\ transformed} =$$

$$\frac{1}{2}\left\{\sqrt{\left(\frac{E_2}{E_1} - 1\right)^2 + 0.333\left(\frac{E_2}{E_1}\right)^2} + 1.151\left(1 - \frac{E_2}{E_1}\right)\right\} \ldots (6)$$

From Fig. 1,—

$$I_{ff} = \left(\frac{T_2}{0.866\,T_1} - 1\right) I_{dD}$$

and since

$$\frac{E_2}{E_1} = \frac{T_2}{T_1}$$

$$I_{ff} = \left(\frac{1}{0.866}\frac{E_2}{E_1} - 1\right) I_{dD}$$

Therefore,—

$$K.\,v.\,a.\ of\ teaser\ auto = 2\,(E_2 - 0.866\,E_1)\,I_{dD}$$

and,—

$$\frac{K.\,v.\,a.\ of\ teaser\ auto}{K.\,v.\,a.\ transformed} = 1 - \frac{0.866}{\frac{E_2}{E_1}} \ldots\ldots\ldots\ldots (7)$$

Equations (6) and (7) give the total k.v.a. rating of the autotransformers, and to put them on the same basis as for a two-winding transformer, the expressions must be divided by two. Therefore, equations (6) and (7) become,—

$$\frac{K.v.a.\ of\ transformer\ parts\ required\ for\ main\ auto}{K.v.a.\ transformed} =$$

$$\frac{1}{4}\left\{\sqrt{\left(\frac{E_2}{E_3}-1\right)^2 + 0.333\left(\frac{E_2}{E_3}\right)^2} + 1.154\left(1-\frac{E_2}{E_3}\right)\right\} \ldots (8)$$

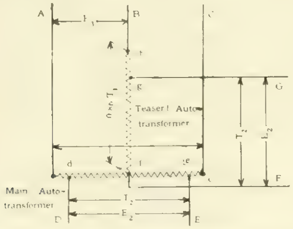

FIG. 3—CONNECTIONS FOR THE CASE WHERE THE TWO-PHASE VOLTAGE IS LESS THAN 86.6 PERCENT OF THE THREE-PHASE VOLTAGE

$$\frac{K.v.a.\ of\ transformer\ parts\ required\ for\ teaser\ auto}{K.v.a.\ transformed} =$$

$$\frac{1}{2}\left\{\left(1 - \frac{0.866}{\frac{E_2}{E_3}}\right)\right\} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

Example—What is the ratio for the main and teaser autotransformers of the k.v.a. rating of the transformer parts required to the k.v.a. transformed, for a ratio of transformation of 2300 volts three-phase to 2300 volts two-phase?

For this case, $\frac{E_2}{E_3} = 1$, and from equation (8),—

$$\frac{K.v.a.\ of\ transformer\ parts\ required\ for\ main\ auto}{K.v.a.\ transformed} =$$

$$\frac{1}{4}\left[\sqrt{(1-1)^2 + 0.333} + 1.154\,(1-1)\right] = 0.144$$

Also, from equation (9),—

$$\frac{K.v.a.\ of\ transformer\ parts\ required\ for\ teaser\ auto}{K.v.a.\ transformed} =$$

$$\tfrac{1}{2}\,(1 - 0.866) = 0.067.$$

2—WHEN THE TWO-PHASE VOLTAGE IS LESS THAN 86.6 PERCENT OF THE THREE-PHASE VOLTAGE:

Fig. 3 shows the two autotransformers connected for this condition. Evidently, the conditions relating to the main autotransformer are the same in this case as in the preceding one, but are different for the teaser. The current I_{tg} is determined as follows:—

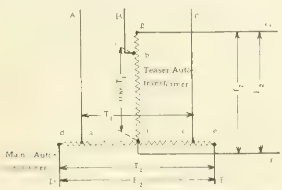

FIG. 4—CONNECTIONS FOR THE CASE WHERE THE TWO-PHASE VOLTAGE IS GREATER THAN THE THREE-PHASE VOLTAGE

$$T_2 I_{tg} = (0.866\,T_1 - E_2)\,I_{aA}$$

$$I_{tg} = \left(\frac{0.866\,T_1}{E_2} - 1\right) I_{aA}$$

The k.v.a. of teaser autotransformer =

$$\left(\frac{0.866\,E_3}{E_2} - 1\right) E_2 I_{aA} + (0.866\,E_3 - E_2)\,I_{aA}$$

Substituting the value of I_{aA} from equation (2) gives,—

$$K.v.a.\ of\ teaser\ auto = 2\left(\frac{E_2}{0.866\,E_3} - 1\right) E_2\, I_{D} \ldots\ldots (10)$$

By the use of equation (5),—

$$\frac{K.v.a.\ of\ teaser\ auto}{K.v.a.\ transformed} = 1.154\,\frac{E_2}{E_3} - 1 \ldots\ldots\ldots (11)$$

Putting this relation on the same basis as for a two-winding transformer it becomes,—

$$\frac{K.v.a.\ of\ transformer\ parts\ required\ for\ teaser\ auto}{K.v.a.\ transformed} =$$

$$\frac{1}{2}\left(1.154\,\frac{E_2}{E_3} - 1\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (12)$$

Example—What is the ratio for the main and teaser autotransformers of the k.v.a. rating of the transformer parts required to the k.v.a. transformed, for a ratio of transformation of 2200 volts three-phase to 1800 volts two-phase?

For this case $\frac{E_2}{E_3} = 0.78$ and from equation (8),—

$$\frac{K.v.a.\ of\ transformer\ parts\ required\ for\ main\ auto}{K.v.a.\ transformed} =$$

$$\frac{1}{4}\left[\sqrt{(0.78 - 1)^2 + 0.333\,(0.78)^2} + 1.154\,(1 - 0.78)\right] = 0.188$$

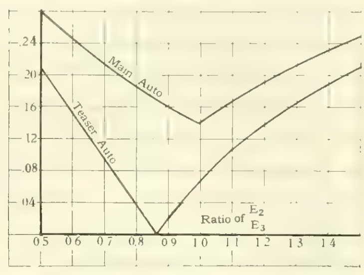

FIG. 5—EFFECT OF VOLTAGE RATIO ON TRANSFORMER CAPACITY REQUIRED

The ordinates represent the ratio of k.v.a. of transformer parts required to the k.v.a. transformed

and from equation (12),—

$$\frac{K.v.a.\ of\ transformer\ parts\ required\ for\ teaser\ auto}{K.v.a.\ transformed} =$$

$$\tfrac{1}{2}\,[1.154 \times 0.78 - 1] = 0.05$$

3—WHEN THE TWO-PHASE VOLTAGE IS GREATER THAN THE THREE-PHASE VOLTAGE

An analysis of this case, the arrangement of which is given in Fig. 4, shows that the current I_{ta} is the same as the current I_{td} in equation (3). The current in the outer ends of the main autotransformer is the two-phase current, I_{dD}. The k.v.a. of the main autotransformer is, therefore,—

$$K.v.a.\ of\ main\ auto =$$

$$\left\{\sqrt{\left(\frac{E_2}{E_3} - 1\right)^2 + 0.333\left(\frac{E_2}{E_3}\right)^2}\,E_3 + (E_2 - E_3)\right\} I_{dD} \ldots\ldots (13)$$

or

$$\frac{K.v.a.\ of\ main\ auto}{K.v.a.\ transformed} =$$

$$\frac{1}{2}\left\{\sqrt{\left(1 - \frac{E_3}{E_2}\right)^2 + 0.333} + \left(1 - \frac{E_3}{E_2}\right)\right\} \ldots (14)$$

Putting this relation on the same basis as for a two-winding transformer it becomes,—

$$\frac{K.v.a.\ of\ transformer\ parts\ required\ for\ main\ auto}{K.v.a.\ transformed} =$$

$$\frac{1}{4}\left\{\sqrt{\left(1-\frac{1}{\frac{E_2}{E_1}}\right)^2+0.333}+\left(1-\frac{1}{\frac{E_2}{E_1}}\right)\right\} \quad \ldots (15)$$

For this case the relation of the k.v.a. of the teaser autotransformer to the k.v.a. transformed is the same as that shown in equation (9).

Example—What is the ratio for the main and teaser autotransformer, of the k.v.a. rating of the transformer parts required to the k.v.a. transformed, for a ratio of transformation of 2300 volts three-phase to 2500 volts two-phase?

For this case, $\frac{E_2}{E_1} = 1.09$, and for the main autotransformer, from equation (15),—

$$\frac{K.v.a.\ of\ transformer\ parts\ required\ for\ main\ auto}{K.v.a.\ transformed} =$$

$$\frac{1}{4}\left\{\sqrt{\left(1-\frac{1}{1.09}\right)^2+0.333}+\left(1-\frac{1}{1.09}\right)\right\} = 0.165$$

and from equation (9),—

$$\frac{K.v.a.\ of\ transformer\ parts\ required\ for\ teaser\ auto}{K.v.a.\ transformed} =$$

$$\frac{1}{2}\left(1-\frac{0.866}{1.09}\right) = 0.102$$

Fig. 5 shows the variation of the k.v.a. of transformer parts required to the k.v.a. transformed for both the main and teaser autotransformers, for ratio of transformations $\frac{E_2}{E_1}$, ranging from 0.5 to 1.5.

Standard Automatic Substation Equipment

R. J. WENSLEY

EQUIPMENT for the automatic operation of synchronous converter substations in railway service has now passed the semi-experimental stage and is considered as a successful means for the reduction of operating costs for electric railways. Standard apparatus is available for the operation of six-phase, 25 and 60 cycle, 600 volt, self starting converters in 300, 500, 750, 1000, and 1500 kilowatt capacities. These may be with or without commutating poles, in the first case being equipped with a motor-driven brush lifting device. Machines of 1200 volts may also be provided with automatic control, although this has not been standardized.

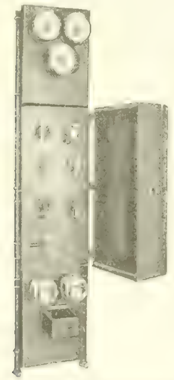

FIG. 1—MASTER RELAY PANEL

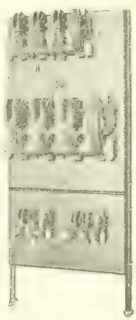

FIG. 2—ALTERNATING-CURRENT PANEL

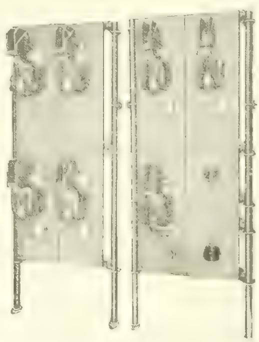

FIG. 3—DIRECT-CURRENT CONTACTOR PANELS

Automatic control can also be successfully applied to motor-started rotary converters, synchronous and induction motor-generator sets, synchronous condensers, and hydroelectric generators.

In the development of the standard apparatus, certain detail changes have been made in the initial equipment.* Every attempt has been made to simplify the apparatus by the elimination of relays and interlock contacts wherever possible.

The standard equipment consists of the following apparatus:—

1—A master relay panel, as shown by Fig. 1, which may be considered as the brains of the control.

2—An alternating-current panel carrying the starting, running and field switches, Fig. 2.

3—A group of direct-current contactor panels for the load limiting resistance and line switch, Fig. 3.

4—A small operating transformer (used only when an oil circuit breaker is provided).

5—An oil circuit breaker with single-phase electrically operated mechanism. Where the machine is small and the primary voltage is high, the cost of the circuit breaker may not be warranted by the saving of core loss in the transformers during the time the station is shut down.

6—A set of resistance grids for limiting the load on the converter.

7—A set of bearing thermostats.

8—A brush lifting device (used only with commutating pole converters).

The wiring diagram, Fig. 4, shows the complete scheme of connections as used in the standard control for six-phase, self starting synchronous converters. The sequence of operations is shown by Fig. 5. This control duplicates as much as possible the manual operation of converters, in that practically all the switch movements are made in response to an electrical change in the converter and not to an external time element or

*See "The Design of Automatic Switching Equipment for Synchronous Converter Substations" in the JOURNAL for April 1918, p.

mechanical sequence of operation, but with the important exception that the automatic control is not apt to make an error of judgment and does not require time to make up its mind to perform a given function. As a result of this swift errorless control, the only minimum limit to the starting time is the acceleration of the converter. A light, high-speed converter with high starting torque may be put on the line from a standing start in 12 seconds.

The standard equipment, as in the earlier forms, is responsive to drop in the trolley voltage, thus receiving its starting impulse when the trolley potential falls below a predetermined amount, usually near 450 volts. The relay performing this function is *1* on the diagram and is the upper left hand device inside the swinging cover, Fig. 1. An induction type potential relay, on the sub-panel of Fig. 1, prevents starting the station with insufficient alternating-current potential. This also introduces a time element of a few seconds to prevent starting the station because of a momentary surge on the trolley. This is relay *2* in Fig. 4.

The master relay *3* is closed from the contacts of *2*,

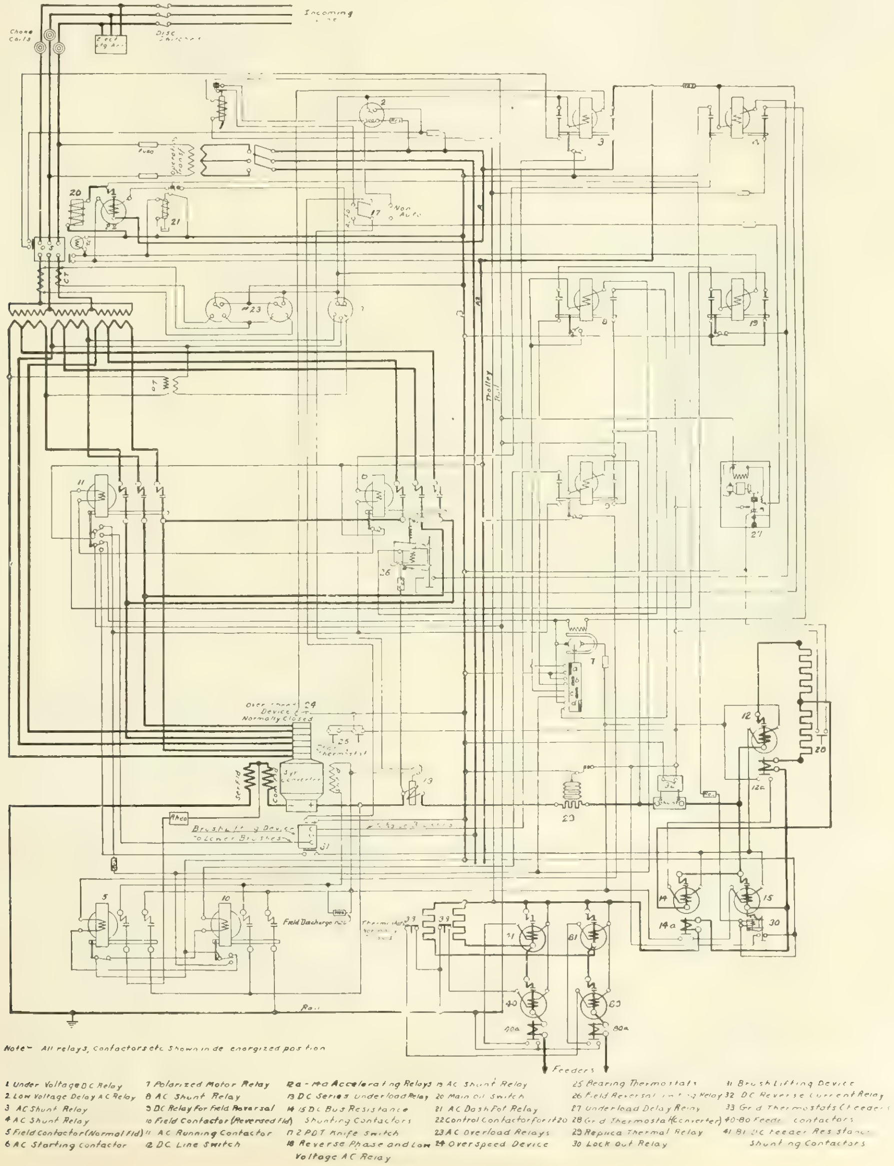

FIG. 4 GENERAL WIRING DIAGRAM

but is locked in independently as soon as its contacts touch. This is the left hand center double contact magnet switch inside the cover, in Fig. 1. The master relay completes the control circuit to the oil circuit breaker mechanism, the field switches, and the starting contactor, and if it is opened for any reason the entire equipment will shut down.

The polarized motor relay *7* is the most important part of the so called "brains" of the control. This relay, Fig. 6, consists of a small motor with a permanent magnet field and a direct-current armature, which is geared through a 200 to 1 reducing gear to a four position drum. The direction of rotation governs the sequence through which the various larger contactors are operated. The motor relay armature is connected to the direct-current brushes during starting. As the potential across the commutator below synchronous speed is alternating, the motor will oscillate but will not revolve. As soon as the converter pulls into step, direct-current is available and the motor starts in a direction dependent on the polarity of the converter.

Sequence Chart

Operation Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	19	20	21	22	27	31	31'	Remarks
1	●						/														●		Station Idle-Trolley Voltage Reduced.
2	●	●					A														●		Relay 2 Closes after 5 Secs
3	●	●	●				B														●		Relay 3 Energizes Aux Control Bus
4	●	●	●	●	●		B												●		●		Normal Field Contactor Closes.
5	●	●	●	●	●	●	B										●		●		●		Converter on Starting Taps-Oil Sw Closed.
6	●	●	●	●	●	●	A↑	●									●	●			●		Polarity of Converter Reversed
7	●	●	●	●	●	●	D↑	●	●								●	●			●		Field Reversing Relay 9 Closed
8	●	●	●	●		●	D/C		●	●							●	●			●		Shunt Field of Converter Reversed.
9	●	●	●	●	●	●	A↓	●									●	●			●		Polarity of Converter Correct.
10	●	●	●		●		B↓				○					●	●	●			●		Converter Connected to Running Taps
11	●	●	●		●		B				●					●	●	●				●	Brushes Lowered to Commutator
12	●	●	●		●		B				●	●				●	●	●				●	Converter Connected to Trolley Thru Full Res.
13	●	●	●		●		B				●	●	●	●		●	●	●				●	Converter Connected to Trolley Thru Part Res
14		●	●		●		B				●	●	●	●	●	●	●	●				●	Converter Connected to Trolley Directly
15		●	●		●		B				●	●		●	●	●	●	●		●		●	Time Delay Under Load Relay 27 Operating
16							B													●		●	Converter Disconnected from AC and DC Lines
17							B														●		DC Brushes Raised to Starting Position

FIG. 5—SEQUENCE OF SWITCHES

The letters in Column *7* refer to contacts made by the polarized relay; the arrows indicate the direction of rotation of the relay.

In case the motor revolves backwards, field reversing relay *9* is energized from the converter armature and locked in independent of the motor relay contacts. This relay opens the main field switch and closes the reverse field switch. The converter direct-current potential then drops rapidly towards zero at approximately which point the field reversing relay opens because potential no longer exists in sufficient quantity to holds its armature in position. This allows the field switches to transfer back to their original positions, and normal operation will cause the converter to slip a pole and come up with reversed polarity. The polarized motor armature will of course stop when the direct-current potential dies away, and will start up again in a reverse direction when the converter polarity builds up after slipping a pole. The drum contacts then revolve in a direction opposite to the above, and cause the starting switch to open, and the running switch to close.

An interlock contact on the running switch then completes the control circuit of the direct-current contactors which close in sequence, short-circuiting the main current limiting resistance one step at a time. Current limit relays *12A* and *14A* are provided so that if the station is attempting to come in on the line when a condition of overload or short-circuit exists, the main contactors *14* and *15* are prevented from closing, thus leaving the main limiting resistance in circuit. These same current limit relays act as overload relays, and open the contactors, thus inserting a limiting resistance, in case of overload or short-circuit after the machine is in full operation.

Automatic operation of synchronous converters demands much more complete relay protection than does manual operation. In a standard equipment the following methods of protection are used to provide against any possible contingency.

Low-Voltage at Starting—Relay *2* is an induction type relay operating on single-phase potential. It is calibrated to close its contacts at 80 percent of normal line potential. In case insufficient potential is present to start the converter, this relay will not close.

Reverse Phase and Phase Failure—Relay 18 is an induction relay having polyphase potential coils. It is operated directly from the power transformer secondaries so that if for any reason polyphase potential of adequate amount and correct phase rotation for operation of the converter is not present, this relay will not open its contacts, and will thus short-circuit the master control relay and cause the station to be disconnected from the line.

Alternating-Current Overload— On equipment with primary voltage of 17 000 volts or less, current transformers and type *CO* relays are used; these being standard induction overload relays. For potentials above 17 000 volts, a series high-tension induction relay is used which obviates the necessity for current transformers insulated for the full line voltage. The overload protection is normally set for 200 percent of normal full load current, and with sufficient time inter-

val to allow the direct-current relays to operate in advance of the alternating-current relays.

Direct Reverse Current—Protection against reversal of energy flow in direct-current circuits is

FIG. 6—POLARIZED MOTOR RELAY

guarded aginst by a dynamometer type of reverse current relay of standard design. This relay has a very heavy shunt field, and a light moving element with the winding energized from an ammeter shunt. If the station is tripped out by the reverse current relay, it will immediately attempt to start, providing demand exists, and the alternating current supply is adequate.

Direct-Current Overload protection is provided by the current limit relays *12A*, *14A*, *40A*, and *80A*. The latter two are in the feeder circuits when used and the first two are in the converter circuits. Where no separate feeders are supplied, one additional relay and contactor are provided in the converter circuit. These relays are set for instantaneous action at approximately 175 percent of normal full-load current. This allows the full ability of the converter to withstand momentary swings to be used to the best advantage. This however, would not protect the converter against continued overloads of less than 175 percent full load. To guard against this contingency, a temperature relay *29*

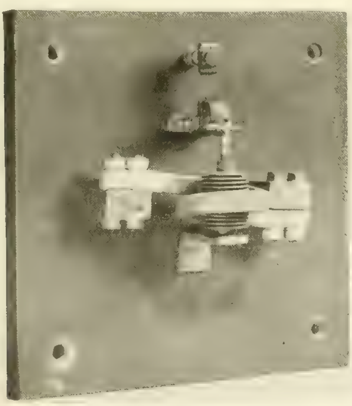

FIG. 7—DIRECT-CURRENT OVERLOAD TEMPERATURE RELAY

is provided which is responsive to the effective heating value of the current passing through it. This relay is composed of a series coil connected in the converter circuits, and a copper bellows filled with volatile fluid Fig. 7. When the series coil has heated sufficiently, due to continued overload, the volatile fluid is vaporized and the bellows expands, thus closing the relay contact and shutting down the station. The station will remain shut down until such time as the cooling of the coil indicates that the machine has cooled down, when the machine will again start if a demand exists.

When the series relays operate, thus opening the direct-current contactors and putting the main resistors in circuit, the grids will get very hot if short circuit or overload persists. A thermostat *28* Fig. 8 is mounted over the resistance grids and when a dangerous temperature is reached, shuts down the station until the grids cool. The station will remain shut down until such time as the series coil has cooled off, thus indicating that the machine has cooled off enough to justify starting again.

Overspeed Protection is provided by the usual centrifugal overspeed device, and is non-resetting. In

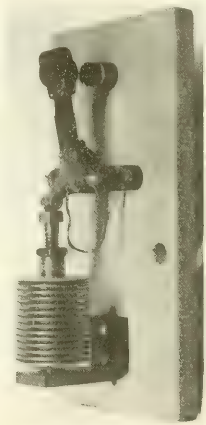

FIG. 8—THERMOSTAT

case of overspeed sufficient to trip the device automatically, the station must be visited by an inspector to reset the trigger and permit further operations.

Bearing Protection—The machine bearings are protected against over heating by thermostats consisting of a copper bulb which is inserted in a hole drilled through the side of the pedestal, the bulb connecting with the copper bellows by copper tubing. The contact device is so arranged that when the heat of the bearing boils the fluid in the bulb, the bellows expand and causes the substation to shut down. After once being shut down by this device, the station will not again restart until the thermostat contact is reset by hand.

For commutating-pole machines, an electrically operated brush lifting device is provided, consisting of an induction motor and reducing gearing with limit switches to prevent overtravel. Interlock contacts are arranged so that the station will not start unless the brushes are completely raised, and the direct-current line switches will not close unless the brushes are completely

lowered. The master control relay *3*, through a back contact, starts the brush lifting operation immediately after the station shuts down. In case the station shuts down due to failure of the alternating-current supply, the brushes of course will not be lifted. When alternating-current supply is again available, even though the trolley voltage is low and demand exists for the station to start, the interlock contacts on the brush lifting device prevent the closing of the master relay *3* until the brush lifting apparatus has reached the end of the travel.

As a result of approximately two years of operating experience with this class of equipment, it has been found that extreme accuracy of calibration of various elements is not necessary. It seems preferable to have relatively rugged devices, rather than delicate relays which are susceptible of calibration within two or three percent limits. Fig. 9 shows the contact making ammeter or current relay used as the underload relay. This is used to hold the station on the line as long as there is demand equal to 15 percent of the station capacity. This relay is typical of the apparatus used on the automatic substation control. The primary voltage relay which furnishes the starting impulse of the station is of exactly similar construction except that it has a shunt coil of a great many turns of fine wire instead of the series coil of bent bar copper

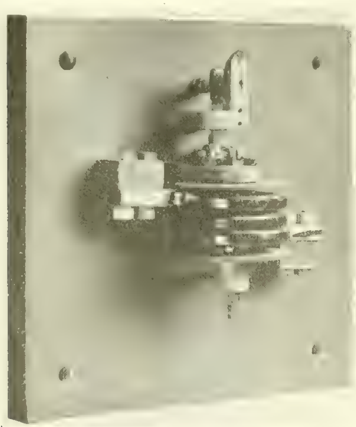

FIG. 9—CONTACT MAKING CURRENT RELAY

The underload relay mentioned above is provided with a contact which is closed in the de-energized position. This contact closes the circuit through the underload delay relay *27*, as shown in Fig. 10. This consists of a small direct-current shunt-wound motor connected through a reducing gearing and magnetic clutch with a moving insulating arm. The coil of this magnetic clutch is connected in series with the motor winding. When the underload relay indicates that less than 15 percent load demand is on the station, this motor starts to run and the magnetic clutch is energized, driving the insulated arm toward a spring contact. If during the time setting of this relay the current demand is again made on the station, the motor will stop and the clutch be de-energized and the spring will return the insulated arm against its back stop. This instantaneous release prevents the time element of the relay from being cumulative. The spring contact, when closed by the arm, short-circuits the coil of master relay *3*, causing the station to shut down. With the motor revolving at approximately 600 to 1000 r.p.m., and with the reducing gearing in the standard relay of 19 800 to 1, calibration can be had from 3 minutes to approximately 20 minutes between the point at which the load drops below 15 percent and the time at which the station shuts down.

This time relay was developed after several different types of time elements had been tried in service, and found wanting. Oil dash pots were found to be entirely too inaccurate for practical operation, due to loss of oil and due to change in viscosity of oil at varying temperatures. Various forms of mechanical time elements were tried with trains of gearing driving small fans operated both by solenoids and by motors. In every case these various devices were found to be unsuited for the rather severe requirements of automatic substation operations.

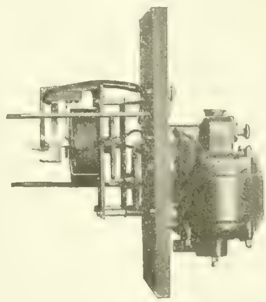

FIG. 10—UNDERLOAD DELAY RELAY

The automatic equipment has been designed in units for location to secure the most economical runs of cable. The alternating-current starting panel is intended to be located as near as possible to a straight line between the transformer secondaries and the converter slip rings. The direct-current group with the grid resistances is intended to be located in the direct run between the commutator end of the converter and the direct-current feeder entrance. The relay panel may be located anywhere that a convenient space may be found, as all the wiring is of small size and relatively inexpensive.

The equipment is intended to be in every sense of the word automatic, and should only require inspection and cleaning approximately once a week. It would undoubtedly operate for a much longer time than this without attention, but to secure best operating results, it would seem advisable to keep within a one week inspection period.

The Insulation of Distribution Transformers

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THE extreme flexibility of the alternating-current system for the generation, transmission and distribution of electric energy is a direct result of the application of the transformer. Transformers permit the power-house to be located where it is most convenient for the generation of electric energy, which is then transmitted at an economical voltage to the point of distribution for power or lighting service. The most economical transmission voltage is a function of the distance of transmission. This is because the loss of energy in a transmission line is inversely proportional to the square of the voltage of transmission, and consequently, if the line losses or line regulation is held constant, the cross-section of the transmission line can be reduced in proportion to the square of the transmission voltage with enormous resultant saving in the amount of copper required.

The distances over which electric energy is transmitted are determined by the location of the point of distribution with respect to the point of generation, and therefore the natural tendency has been to introduce an unlimited number of transmission and distribution voltages, and the demand has been for an equally varied number of transformer voltages. A transformer, indeed, may be considered as a flexible link in the chain between the alternating-current generator and the incandescent lamps, heating appliances, fans, motors, furnaces and other domestic or industrial devices which utilize electric energy for their operation.

FIG. 1 — SHELL-TYPE TRANSFORMER
With concentric rectangular coils.

FIG. 2—CORE-TYPE TRANSFORMER
With concentric rectangular coils.

For distribution systems, the standardization rules of the National Electric Light Association and of the Electric Power Club list the following voltages:—440, 550, 2300, 4600, 6600, 11 000, 13 200, 22 000, and 33 000, and these, together with the twelve to fifteen capacity ratings for each voltage class, present a great variety of conditions for the application of insulation. For lighting or domestic service, electric energy is usually supplied at voltages limited to about 115 or 230 volts and for industrial or motor service to about 115, 230, 460 or 575 volts, these secondary voltage limitations being drawn because of safety requirements in the operation of the apparatus.

All of the above simply emphasizes the extent and variety of the insulation problem in the design and manufacture of distribution transformers. Necessarily the paramount consideration in the design of distribution transformers is that of safety. To insure reasonable voltage regulation, the high and low-voltage windings are of necessity in close proximity and in consequence the strength and permanence of the insulation between these windings has an importance that cannot be over-emphasized. Indeed the safety of every user of electric light and power may be said to be dependent upon the integrity of the insulating barrier between windings in the transformer, through which the energy is supplied.

In view of the importance of transformer insulation from a safety standpoint it is a gratifying fact that the modern distribution transformer embodies this requirement to an extremely high degree and the description following shows how the possibility of failures has been guarded against in some modern designs using concentric rectangular coils (Figs. 1 and 2). With this type of coil construction, the same general scheme of insulation is used for the transformers up to and including 200 k.v.a. and 22 000 volts except that the subdivision of the coils and the insulation distances are increased for transformers of the higher voltages. The important points to consider in the application of transformer insulation are as follows:—

a—Between the high and low-voltage windings.
b—Between the complete set of windings and the magnetic circuit.
c—Between the individual turns and layers of the windings.
d—Between the coil sections of each winding.
e—Between the coil leads and taps and the windings.
f—Between the high and low-voltage leads and the tank. The leads have also to be insulated, separated and supported between the coils and the bushings in the tank.

It is an obvious essential that the insulation between the high and low-voltage windings must be practically failure-proof, so that even under the most severe conditions of short-circuit or overload which can occur and which may reduce the windings to a mass of charred insulation and copper wire, the insulating barrier will maintain its integrity and prevent the high-

voltage from breaking across to the low-voltage coil. The material selected for this purpose must, therefore, be capable of sustaining a high temperature without injury, and for this reason micarta and mica-micarta tubes are used in the transformer under consideration. Micarta tubes have been used for several years between the high and low-voltage windings of distribution

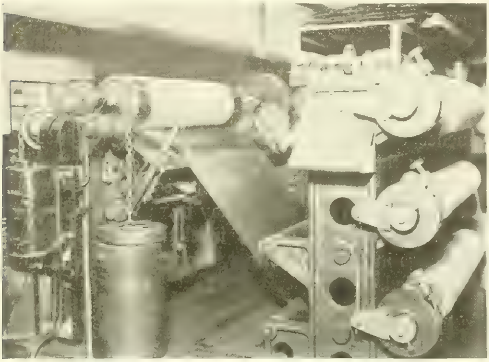


FIG. 3—MACHINE FOR THE MANUFACTURE OF MICA-MICARTA INSULATING TUBES

transformers with this type of coil construction, and the excellent service record that has been obtained is conclusive evidence of the reliability of the insulation that has been provided.

The micarta tubes are made by a special process. In the manufacture of the tubes, micarta paper coated with a shellac bond is wound between steel rolls under heat and pressure on a steel mandrel as shown in Fig. 3. The bond is melted by the heat, and the pressure between the rolls compresses the paper solidly together, all air and moisture being sealed out. Built-up mica sheets are fed between the layers of paper as it is wound on the mandrel, so that approximately fifty percent of the finished tube is pure mica, which is held firmly between the layers of insulating paper. The micarta cylinder is then forced off the roll by a hydraulic press and is cut up into desired lengths by a circular saw. After being reheated in an oven to soften

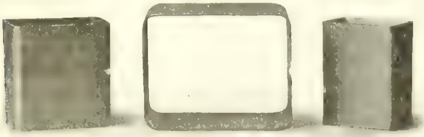
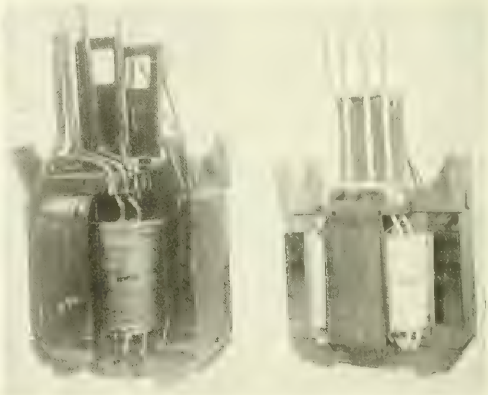


FIG. 4—COMPLETED MICA-MICARTA TUBES

the bond, the cylindrical tubes are then formed by wooden moulds into their final shape, as shown in Fig. 4.

This method of manufacture provides a tube having maximum dielectric strength for a given thickness of material. As an illustration of the remarkable strength of this insulation the barriers, used with 2300 volt transformers, which are approximately only 3/32 inch thick will withstand a puncture test under oil of between 40 000 to 50 000 volts.

The great advantage of this method of applying sheet mica, is that the mica goes into the tube without wrinkles, and thus insures a uniform insulating barrier, free from flaws. The micarta paper reinforces the mica and gives it the mechanical strength which is lacking in plain mica, while the tube has the heat-resisting qualities of high-grade mica lacking in plain paper. It should be noted that a solid barrier of this type provides insulation which is just as effective at the corners, both mechanically and dielectrically, as along the straight part of the winding, and which gives uniformity to the coils and maintains them in the proper relative positions without warping. Coils wound over these tubes have their layers uniform, so that there is no tendency to cut the insulation between layers under the expansion and contraction incident to the rise and fall of the coil temperature with change of load.



FIGS. 5 AND 6—TRANSFORMERS AFTER AND BEFORE IMPREGNATION

A fact that is not immediately obvious is that in the construction of a transformer, where fibrous insulation is employed, the safety of the transformer is not necessarily increased by heavily padding the windings with insulation, but that on the contrary, the smaller the quantity of fibrous insulation used to secure the requisite dielectric strength, the more effectively is a transformer insulated from a safety standpoint. This follows directly from the fact that all insulators of electricity are insulators of heat. Consequently mere quantity of insulation is far from being ideal and too heavy insulation may defeat its own object by setting up barriers to the flow of heat from the winding to the oil. This is an important consideration, inasmuch as fibrous materials, such as cotton, treated-cloth, paper and fullerboard cannot be operated continuously with safety at a temperature in excess of 105 degrees C.

Unless, therefore, the insulation is skillfully applied, heat insulating barriers may cause local heating or hot spots in the windings, with disastrous effects on

the fibrous insulation, which will char or carbonize and thus cause short-circuits which may ultimately destroy the entire winding. Mica, while it resists high temperatures, and is indeed ideal for tubular insulation, cannot be used between turns and layers. With the pres-

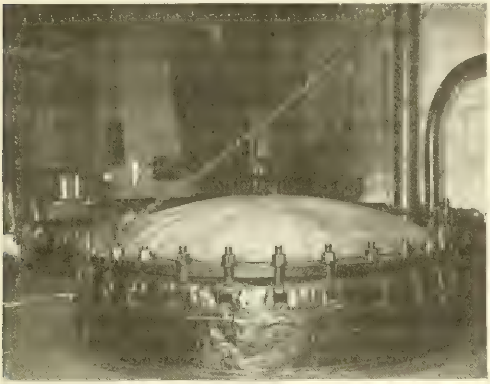


FIG. 7—IMPREGNATION TANKS

ent development of the art, fibrous materials are indispensible for such service, both because of the ease with which they can be applied and because of the facility with which these materials absorb impregnating compounds. The coil must therefore be so made as to insure that the maximum operating temperature will not cause deterioration of this type of insulation.

The distribution transformers herein described are subjected to an impregnating treatment which has reached a high degree of perfection after many years of exhaustive research and practical experience in its application. The transformers are first assembled complete for mounting in the tanks except for the porcelain terminal blocks or spacers, as shown in Fig. 5. The assembled units are then placed in an oven through which a current of heated air is circulated. After this preliminary drying-out process, the transformers are lowered into a steam-heated tank, Fig. 7. The cover of this tank is bolted on and a vacuum is

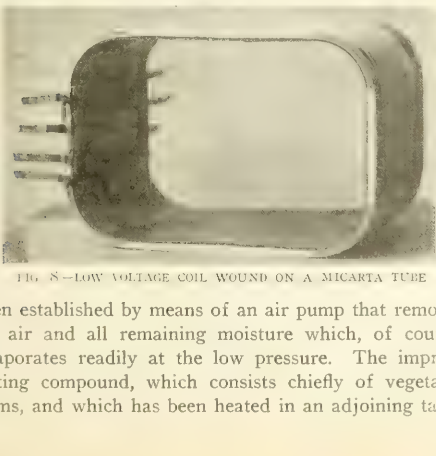


FIG. 8—LOW VOLTAGE COIL WOUND ON A MICARTA TUBE

then established by means of an air pump that removes all air and all remaining moisture which, of course, evaporates readily at the low pressure. The impregnating compound, which consists chiefly of vegetable gums, and which has been heated in an adjoining tank, is then admitted to the vacuum tank until it completely covers the coils. The air and moisture having previously been removed, the compound, assisted by capillary attraction, enters freely into all the interstices of the windings, but to insure the most thorough penetration an air pressure of over 80 pounds per square inch is applied in the tank, and this is left on for several hours. The remainder of the compound is then withdrawn from the impregnating tank, the transformers are lifted out and placed in a vertical position to cool.

As a result of this treatment the windings are transformed into a solid mass of copper and insulation, and the following specific advantages result:—

1—The insulation strength of the windings between individual turns, layers and coil sections and between the coils and the iron reaches a very high value. The necessary insulation distances are provided by the cotton-covering and other fibrous materials, and these materials readily absorb the impregnating compound which possesses extremely high dielectric strength.

2—The heat conductivity of the windings is greatly improved; this helps to eliminate hot-spots and produces a uniform temperature rise.

3—In the vacuum treatment all air and moisture is removed and the impregnating compound then acts as a seal, so that the windings will not readily absorb moisture.

4—The mechanical strength of the windings is increased, giving greater insurance against mechanical shocks due to short circuits.

The compound used for the impregnation is not soluble in oil at the operating temperature of the trans-

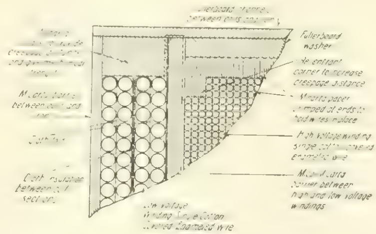


FIG. 9—CROSS SECTION OF CORNER OF SMALL CAPACITY CONCENTRIC COIL TRANSFORMER

formers and therefore does not clog up the ventilating ducts after the transformers have been placed in service. The melting point also is such that it will not soften under the usual operating temperature to which distribution transformers are subjected.

In the design and construction of these rectangular concentric coil transformers, the insulation has been compressed into the smallest possible space and so disposed as to provide the least possible resistance to the flow of heat from the coils. That this has been accomplished in the case of the micarta barriers is readily apparent from the previous description and similar results have been secured in connection with the application of the fibrous insulation used between turns, layers and coil-sections.

Various methods of applying the insulation are employed, depending upon the size and shape of the wire to be insulated and the capacity and voltage of the transformer. For example, the high-voltage coils of the smaller size transformers are all wound with round wire. On the other hand, the low-voltage coils and the

high-voltage coils of the larger capacities are wound with copper strap, and the insulation of the coils using copper strap is fairly simple, particularly when the coils are wound directly upon micarta tubes, as shown in Fig. 8. The end turns of these coils are tied in position, cloth and paper insulation are used between layers, and the ends are padded with micarta collars, both to give mechanical strength and to provide the necessary creepage distance between windings. The insulation provided is very effective and the mechanical strength of the coil is excellent.

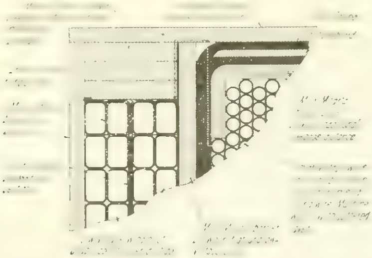


FIG. 10—CROSS-SECTION OF CORNER OF MEDIUM CAPACITY CONCENTRIC COIL TRANSFORMER

Considerable skill has been employed in the insulation of high-voltage windings, using round wire. Where the very smallest wires are involved, the construction shown in Fig. 9 has been employed. The layer insulation is of paper, crimped at the ends to hold the wires in position, and with re-entrant corners to give increased creepage distance indicated by the broken line. With larger-size round wires, a very ingenious construction is employed, the details of which are as shown in Fig. 10. The high voltage coil is subdivided into four sections, each section being separately wound and taped as shown in Fig. 11. The wire is insulated with cotton covering and enamel and on account of the reduced stress between layers due to the subdivision of the winding additional layer insulation becomes unnecessary except at the corners. This permits a machine winding with guttered layers, in which each wire is placed in a gutter between two other wires. The advantage of the guttered winding as compared with the usual construction is shown in Fig. 12 from which the saving in space is readily apparent.

FIG. 11—MACHINE-WOUND HIGH-VOLTAGE COIL
Partially complete, showing micarta channel pieces.

These machine-wound coils are very strong mechanically. The method of insulation insures very thorough penetration of the insulating compound, with resultant uniformity of temperature, while in any case the possibility of the chafing of one wire or layer on another, due to temperature differences causing unequal expansion or contraction in the winding is prevented by the manner in which each wire is held solidly between six other wires.

The high-voltage coil sections are insulated from each other by fuller-board washers and channels of mica-micarta insulation are placed over the ends of the winding to provide a large creepage distance to the iron or the low voltage winding, as indicated by the broken line in Fig. 10.

Similar methods of insulation are employed in the insulation of these concentric coil transformers regardless of voltage class, except that with higher voltages, a larger number of subdivisions of the high-voltage winding is necessary and greater insulation distances are required. Furthermore with higher voltages extra heavy padding of the end turns is provided to protect against high-frequency line surges.

The coils of all of the transformers under discussion are concentric, the inner and outer coils forming the low voltage winding, the high voltage winding being placed between them. The great advantage of this type of construction for small transformers is the ease of applying tubular insulation between the coil surfaces.

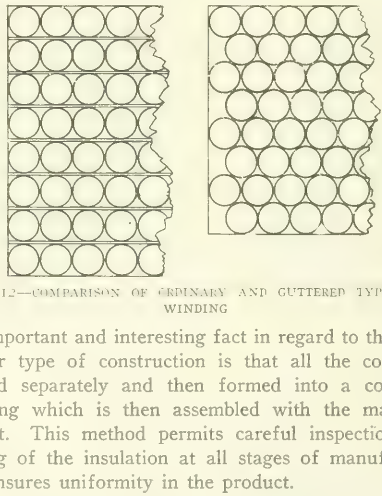


FIG. 12—COMPARISON OF ORDINARY AND GUTTERED TYPES OF WINDING

An important and interesting fact in regard to this particular type of construction is that all the coils are wound separately and then formed into a complete winding which is then assembled with the magnetic circuit. This method permits careful inspection and testing of the insulation at all stages of manufacture and insures uniformity in the product.

The leads or taps from the coils are insulated from the windings by means of micarta barriers and are brought out through a treated-wood spacing block to a porcelain spacer or terminal block. Porcelain terminal blocks are supplied when it is necessary to provide for taps, and in this case the terminal blocks are submerged below the oil level to prevent flash-overs across the brass studs to the case from lightning surges. Porcelain spacers are provided when no taps are brought out, and it is simply necessary to separate and support the leads. In this case the porcelain spacers are placed at the oil level, and protection against flash-overs is provided by the insulation on the high-voltage leads.

From the terminal blocks or spacers the leads pass to porcelain bushings which are babbitted in the tank.

The function of the bushings is to provide leakage distance for the prevention of flash-over from line surges and to reinforce the lead insulation against the ordinary voltage stresses. These bushings are made from high-

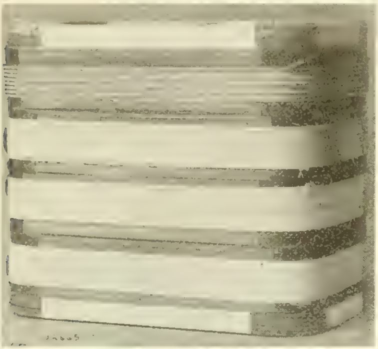


FIG. 13—HIGH VOLTAGE COIL OF CONCENTRIC COIL TRANSFORMER
Showing reinforced winding.

grade, homogenous porcelain and are thoroughly glazed. The flash-over distances are generous and the perfectly smooth surfaces, placed in an inverted position, do not offer positions where soot or dirt can readily accumulate.

The leads are flexible stranded copper cable insulated with treated cloth which has been treated with a weather proof gum. The leads are sealed into the bushing by a compound which renders the joint moisture and oil proof.

A 2300 volt bushing is shown babbitted in its position in the case in Fig. 14. The lead after being cut to the right length is wound with gilling thread and is then pulled through the bushing. The sealing com-

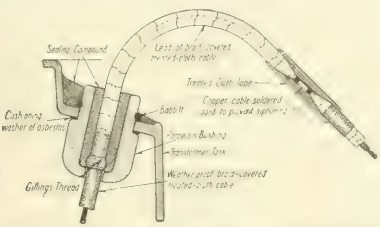


FIG. 14—LEAD AND BUSHING FOR 2300 VOLT TRANSFORMER

pound, is poured around the bushing and into the recess in the bushing, making a thoroughly weather proof joint.

A bushing used for 4600 and 6900 volt transformers is shown in Fig. 15. The insulation distances are greater than with the 2300 volt bushing, and in addition an elbow is provided at the top to give additional insulation between the lead and the case and to support the lead between the bushing and terminal block. The bushings used for 11 500 and 13 800 volt transformers, are similar, but in this case a petticoat is provided to increase the insulation distances. The single groove is made wide and smooth and the inverted position prevents the accumulation of dirt and soot.

The 23 000 volt bushing consists of a single bell-shaped porcelain insulator which is fastened into a standard pipe bushing with cement. The lead is wrapped with gilling thread and pulled tightly into the bushing, and the sealing compound makes a moisture proof joint. During shipment the bushing and lead are removed to prevent breakage and a plug is used to close the hole in the case.

Insulation failures may result from a variety of causes. Probably the most frequent, aside from overloads, are caused by high-frequency line surges; hot

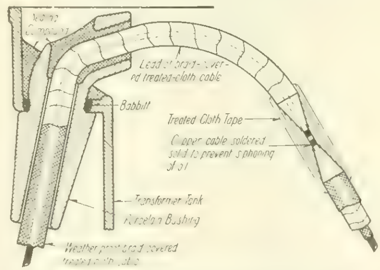


FIG. 15—LEAD AND BUSHING FOR 4600 AND 6900 VOLT TRANSFORMERS

spots or unequal temperature in the winding; and water soaked insulation. The foregoing description shows the care that is taken in a modern distribution transformer to insure against trouble from these causes. Safety and reliability have indeed been built into the modern design, and the percentage of failures from all causes is remarkably small. Better protection of these transformers by a more elaborate use of lightning arresters and periodic testing and inspection of the oil for the presence of moisture which transformers sometimes breath into the case would undoubtedly reduce the number still farther. It is safe to assert, however, that no one piece of apparatus is subjected to less care and inspection in service than the distribution transformer, and its service record under these unfavorable operating conditions has been little short of remarkable.

The Electrostatic Glow Meter

R. J. Wensley

IN HIGH TENSION switching stations where no wattmeters are used, it is often desirable to have an indication of the presence of potential, indication of grounded phase, or of synchronism between two separate high tension lines. Where no potential transformers are needed for other purposes, it becomes

FIG. 1—FRONT VIEW OF GLOWMETER

very expensive to provide the above indication. A simple device for securing these indications through the electrostatic discharge of one section of an insulator column has been developed, thus obviating the necessity for potential transformers.

Fig. 1 is a front view of this device, and Fig. 3 is the same device with the cover removed. The base on which the apparatus is mounted is of micarta insulation. The indicating device consists of three small bulbs filled with a rare gas which has the property of giving

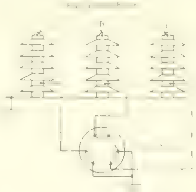


FIG. 2—CONNECTIONS FOR THE GLOWMETER
When used as ground detector.

forth a vivid orange red glow on an extremely small static discharge. These bulbs are sprung in between spring clips and are separated from one another by micarta tubing which may be seen inside the cover of the instrument. This device is connected as shown in Fig. 2 when used as a potential indicator or ground detector. It will be noticed that one bulb is in parallel with the bottom section of each of the three insulator columns.

When used for synchronizing between a bus and a line or between two lines or two busses, the glow meter is connected as in Fig. 4. When used for this

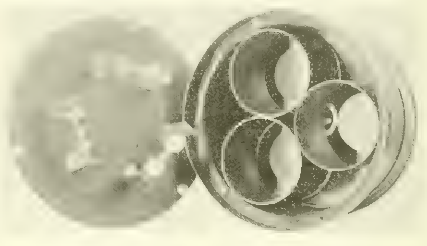


FIG. 3—GLOWMETER WITH COVER REMOVED

purpose, the phase connections through the top lamps are made so that the lamp will be out at synchronism. The phases to the two lower lamps are crossed so that they will burn at half brilliancy at synchronism. When out of synchronism there will be an apparent rotation which will be an indication of whether the incoming line is fast or slow.

For switching these instruments small oil switches are used, and it is possible to use one glow meter for a number of purposes by providing enough oil switches. The connecting leads may be run considerable dis-

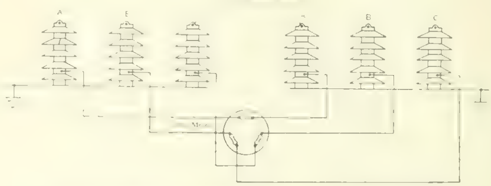


FIG. 4—THE GLOWMETER USED AS A SYNCHROSCOPE

tances if carefully insulated and may be carried into buildings if treated as wiring for 2200 volts. The glow meter should preferably not be mounted on the switchboard, but may be mounted above it on a bracket or on the wall or other suitable location. So far as is known, there is no limit to the useful life of the bulb.

THE ELECTRIC JOURNAL

INDUSTRIAL APPLICATIONS OF ELECTRIC HEATERS

MAY 1919

Electrically-Heated Metal Pattern Plates on Molding Machines

To produce clean, smooth castings from molds made with metal patterns there must be no sticking of the molding sand to the patterns when they are removed from the sand. There is a tendency for moisture to collect on the cold metal pattern from the moist sand, or for the cold plate to sweat, during which process moisture collects on it. When this moisture collects, the sand sticks to the pattern when it is removed from the mold, and the mold acquires a rough surface, so that when the metal is poured, the casting will have a rough surface. This pattern will now have a rough surface due to the adhering sand, so that when the next mold is made, it will have a rough surface unless the pattern is cleaned off and dried. This trouble is experienced in both summer and winter.

The collection of moisture can be prevented by heating the pattern. The heat applied, however, must not be so great as to cause the sand in the mold to dry, as it would then crumble away and again the casting would have a rough surface. Furthermore, the heat must be applied in such a way that the pattern can be changed conveniently when desired. The usual method of heating is by means of a gas flame left burning in the space underneath the pattern within the frame work of the molding machine. It is difficult to keep the flame low enough so that it will not heat the pattern too much. A larger flame than necessary is often employed at some distance from the surface of application. This makes an inefficient arrangement, as most of the heat is dissipated into the surrounding space. The surrounding air becomes contaminated by the gas fumes, and in summer, there is the further discomfort due to the heating of the surrounding air. Difficulty is experienced due to variation of gas pressure, so that at one time the pattern is too hot and at another, too cold. When the pattern gets too hot, it is necessary to cut off the gas, and when it has cooled down, relight and readjust the gas.

A much more convenient method of heating is by the use of electric heaters as shown in Fig. 1. Two steel-clad heaters are mounted in the space immediately below the metal pattern plate, within the framework of the molding machine. In order to use as little heat as possible, they are located just below the thickest pattern used. They are attached to supporting angles attached to the frame of the machine. It is obvious, then, that any pattern of any thickness and of any size within the capacity of the machine may be attached to or removed from the molding machine without being interfered with by the heaters, and without disturbing the heaters. To conserve heat, an asbestos insulating plate is placed just below the heaters, to prevent loss of heat due to radiation downward from the heaters. The entire installation is made in such a way as not to interfere with the usual operation of the machine, including the mechanical vibrator, and without any modification of the machine other than to drill and tap small holes for attaching the mounting angles.

The heaters are of the steel-clad type. For the molding machine shown, taking a pattern plate 16 by 11 by 2 inches, there are two heaters each 13 inches long, 2¼ inch wide and ¼ inch thick over all. They consist of slotted ribbon resistors of high resistance, temperature-resisting alloy insulated in mica troughs, the whole being encased in a heavy sheet steel casing. The heater terminals are mounted on one end of the heater casing, and are protected by a substantial terminal cover. The two heaters used on each machine have a total rating of 300 watts, and operate on 110 volts. The heaters are connected permanently together electrically, and connection is made from a wall receptacle to the machine by means of a flexible heater cord having a separable attachment plug on the end.

Because of the small space in a vertical direction occupied by the heaters, there is ample room for them in the somewhat restricted space available; and due to the flexible heater cord, it is possible for the pattern support to be raised or lowered, the heaters moving as an integral part of it.

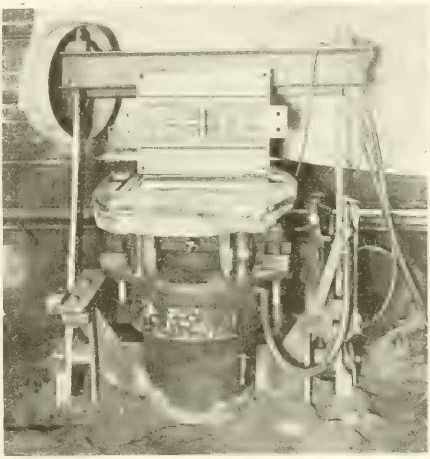


FIG. 1—MOLDING MACHINE EQUIPPED WITH ELECTRIC HEATERS

The advantages of this method of heating over the use of gas are obvious. When it is desired to heat the pattern plate, it is not necessary to hunt for a match, operate valves, or adjust valves until the correct degree of heat is obtained. Instead, it is only necessary to plug into a wall receptacle and give no further thought to the matter, since but one degree of heat, and that the correct one, can be obtained. If for any reason, such as the machine standing idle, the pattern plate should be over-heated, it is not necessary to operate any valves, such as shutting off the gas, until the temperature becomes right and then re-light and re-adjust the valves. Instead, it is only necessary to pull the plug from the wall receptacle and leave the heater disconnected until the temperature becomes right, and then plug it in again. Furthermore, no trouble is experienced from variation of gas pressure, and a steady, uniform heat is obtained.

R. A. BOLZE.

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country.

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

MAY 1919

Railway Motor Testing—V

LOCATING AND REPAIRING ARMATURE WINDING TROUBLES

GROUNDS

Partial Grounds can be located by using the testing box Fig. 1, or lighting-out line Fig. 4 (R.O.D. Jan. '19), by keeping the current from the testing circuit on the armature until the insulation gets hot and smokes, when the ground can be located. The damaged coil, when located, should be re-insulated and put back in place, or replaced by a new coil.

Dead Ground—This type of ground cannot be located by the above test. Connect a telephone receiver set as shown in Fig. 19, which will give a buzzing sound in the receiver. Move the terminal from the receiver around over the surface of commutator until a point is reached when the buzzing sound disappears. The coil connected to this commutator bar will be the grounded coil.

This same test can be made by using a 500 volt trolley circuit connected through a headlight resistance, instead of the battery circuit, and replacing the telephone receiver by a small square coil (made up of approximately 300 turns of about No. 30 wire) set on edge with a compass needle placed in the center of the coil. The needle will not deflect when the commutator bar with the grounded coil is located.

All of the work outlined below is done in connection with the portable armature testing yoke, Fig. 2, and lighting-out line Fig. 4. (R.O.D. Jan. '19).

OPEN CIRCUITS

Tests—Magnetic—No indication by this test.

Sparking—Two adjacent commutator bars will give a bright blue spark. Same condition will be found diametrically opposite.

To Locate—Remove the top leads from three commutator bars on one side and from two commutator bars on the other side. Place one terminal of the lighting-out line on the coil leads and the other terminal on the commutator bar to which the other end of this coil is connected. If the lights do not burn, this coil is open circuited.

To Repair—If the place where the coil is broken can be located, being in the lead or exposed surface of the coil, the wires can be spliced. If the break cannot be found, remove the coil and replace by a new one.

CROSSED LEADS—SINGLE CONDUCTOR PER COIL

Tests—Magnetic—Shows on armature core at four slots spaced about one-fourth the way around the armature.

Sparking—One commutator bar will be found that gives no spark when short circuited to the adjacent bars on both sides. The same condition will be found diametrically opposite.

To Locate—Lift the top leads from five bars at one of these places, and from three bars at the other point. Light out the leads.

To Repair—Place the leads in proper commutator bars and resolder.

DOUBLE CONDUCTORS PER COIL

Sometimes when the leads are in parallel in putting on the sleeving, the leads may be paired wrong. This generally happens to the bottom leads.

Tests—Magnetic—Same as above.

Sparking—Same as above, except you will get a faint spark instead of no spark.

To Locate—Same as above.

To Repair—Pair the leads properly, insulating the wire where the reversed cross is made, place in the proper commutator bars and resolder.

SHORT CIRCUITS—BETWEEN TURNS OF SAME COIL

Tests—Magnetic—On the core only one slot is magnetized. When the commutator is at the right, this indicates that the top coil in this slot is the defective coil.

Sparking—No indication.

To Locate—Remove the commutator end band and test. If it is still short-circuited, remove the pinion end band and test. If it is still short-circuited with the exciting current on, and a piece of sheet iron over the armature slot, containing the short circuited coil, by means of a screw driver shift the leads and wire at the ends of the coil. The piece of sheet iron will drop off when the wires that are short circuited are separated. When the short-circuit disappears, search at the point of last operation for the trouble.

To Repair—If trouble can be located, repair the damaged insulation and reband. If unable to locate the short-circuit, remove the defective coil and replace it by a new one.

BETWEEN ADJACENT COILS OR COMMUTATOR BARS

Tests—Magnetic—Shows on armature core at four slots placed about one-fourth way around the armature.

Sparking—Between two adjacent bars, there will be no spark, and diametrically opposite, there will be a faint spark between three adjacent bars. This indicates that the short-circuit will be between or near the two bars that show no sparking.

To Locate—Clean the exposed mica between the dead commutator bar and test. If it is still short-circuited, lift the top leads from the two bars that do not spark and the top leads from the three bars showing the faint spark. With the lighting-out line, test the leads for short-circuits. Mark the leads that show short-circuits, then lift the bottom lead of one of these marked coils in the commutator. Test with lighting-out line between the disconnected commutator bar and the one to which the other short-circuited coil lead is connected. This will show whether the trouble is in the commutator or the coil.

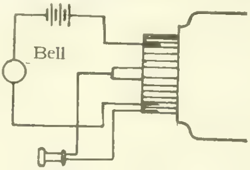


FIG. 19—TELEPHONE TEST SET

To Repair—If the short-circuit is in the commutator, examine the mica again very carefully. If the trouble cannot be located, it will be necessary to take out the front commutator V-ring and remove the two short-circuited commutator bars. Careful examination will usually reveal the trouble which is mostly due to carbon dust, dampness, metal chips, solder or defective insulation.

If the trouble is in the coil proceed as outlined under "Between Turns of Same Coil."

BETWEEN COILS NOT ADJACENT (1 to 3, 4 OR 5)

Tests—Magnetic—Shows on armature core in four groups of slots spaced about one-fourth way around the armature. The number of slots varies, depending upon the location of the short-circuit.

Sparking—Between 2, 3, 4 or 5, adjacent bars faint sparking will be noticed. The same condition occurs diametrically opposite.

To Locate—Proceed in the same way as above "Between Adjacent Coils or Commutator Bars," except lift more leads on each side of the commutator bars. With lighting-out line test each lead with every other lead until the short-circuit is located.

To Repair—Same as given under "Between Turns of Same Coil."

BETWEEN COILS NOT ADJACENT (1 to 10, 15 OR 25)

This trouble is generally found to occur at a point where the leads of one coil come in contact with the end extension of another coil.

Tests—Magnetic—Show on the armature core in four groups of slots spaced about one-fourth the way around the armature. The number of slots varies depending upon the location of the short-circuit.

Sparking—Between a number of commutator bars faint sparking will be noticed. The same condition in four groups located about one-fourth the way around the armature. Some times some of these bars will be dead.

To Locate—Disconnect all of the top leads raising them just high enough to clear the commutator. With fine copper wire make a turn around each lead to connect all the leads together. With a lighting-out line test between each lead and the entire group as you separate them, until one of the short-circuited leads is located. With the terminal on the lead, that is short circuited, test the balance of the group until the other short circuited lead is located. Mark these two leads and bend back, then test again and if the short-circuit disappears the trouble was on the top lead. If the coils are still short-circuited locate and mark the commutator bars to which the short-circuited leads are connected. Follow the bottom leads from these commutator bars back under the winding, lifting the windings until the short-circuit is located.

To Repair—Same as given under "Between Turns of Same Coil."

PARTIAL SHORT-CIRCUIT

Sometimes conductors become partially short-circuited which shunts a portion of the current only.

Tests—Magnetic—Shows on armature core at four slots spaced about one-fourth way around the armature.

Sparking—Between two adjacent bars there will be faint sparking with the same indication on three bars diametrically opposite.

To Locate—Lift the top leads from three bars on one side and from two bars on the opposite side. With lighting-out line locate the short-circuit.

To Repair—Same as given under "Between Turns of Same Coil."

JAMES W. MCCORKLE

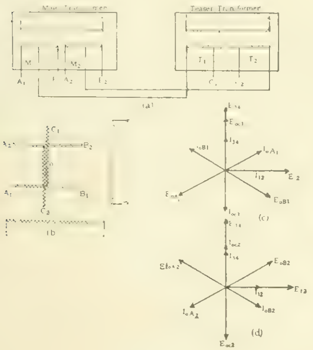
THE JOURNAL QUESTION BOX

OUR subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. The topics should be of general interest; information involving the specific design of individual pieces of apparatus is not supplied. Care should be used to include all data necessary for an intelligent answer.

A PERSONAL reply is mailed to each questioner enclosing a stamped, self addressed envelope as soon as the necessary information can be obtained. Anonymous questions cannot be considered. As each question is answered by an expert on the subject involved, and checked by at least two others, a reasonable length of time should be allowed before expecting an answer.

1741—PHASE TRANSFORMATION — Please give the connections necessary for a transformation from two phase to six phase diametrical; also from two phase to six phase double delta. What is the vector relation between the currents and voltages of the high and low tension sides of the transformer in each case? G.MC. (N.Y.)

A six-phase relation can be obtained from a two-phase line with two transformers, using a double Scott connection, but this transformation cannot be said to be "six-phase diametrical" or



FIGS. 1741(a) to (d)

"six-phase double delta." Fig. (a) shows the scheme of transformer connections. Fig. (b) shows the primary and secondary windings of the main and teaser transformers in their phase positions. Fig. (c) shows the vector relations of current and voltage in M_1 and T_1, and Fig. (d) in M_2 and T_2, assuming a load of unity power-factor. W.E.D.

1742—TRANSFORMER CONNECTIONS FOR ROTARY CONVERTER—When it is desired to change the direction of rotation of a six-phase rotary converter, and it is impracticable to change the primary transformer leads, how may the desired result be obtained by interchanging the secondary leads to the machine? Give diagrams (a) double delta (b) double star (c) diametrical. Three single-phase transformers are used in each case. J.G.C. (MD.)

The direction of rotation of a rotary converter can be changed most readily by changing the connections of four of the primary leads to the line as shown in the following diagrams. The connections of Fig. (b) will give a direction of rotation the reverse of that of Fig. (a). The same changes will produce a reversal regardless of the secondary connections. If this is not feasible, the direction of rotation may be changed by reversing the order in which the cables are connected to the slip rings as shown

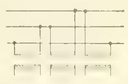


FIG. (a)

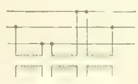


FIG. (b)

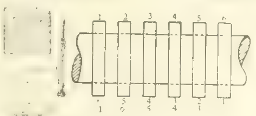


FIG. (c)

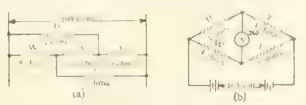
in Fig. (c), in which the numbers above the rings represent the order for one direction of rotation, and those just below the rings, the opposite direction. Since it makes no difference which cable is connected to any particular ring, so long as they are connected in the proper order, it may be easier to connect them according to the second set of numbers below the rings, which are in the same order, but leave cables *1* and *4* connected to the same rings as before. W.M.M.

1743—GENERATOR EFFICIENCY—In determining the efficiency of the prime mover in a hydroelectric unit would it be proper to use the generator efficiency in connection with the measured output of the generator to arrive at the output of the wheel? I ask this question for it seems to me that the field copper loss, not being a loss due to rotation, should not be credited to the wheel output. The above item may not amount to very much in some machines but I have in mind a small, low-speed alternator, in which this would be quite a factor. O.A.F. (ME.)

The conventional efficiency of the generator should not be used to determine the output of the waterwheel. If the excitation is furnished by a separately-driven exciter the waterwheel does not supply the field loss which, of course, is included in the generator efficiency. If there is a direct-connected exciter, the waterwheel supplies the loss in the field, but in addition it supplies exciter losses which are not included in the generator efficiency. To find the output of the waterwheel it is necessary to work out an efficiency based upon the losses which it supplies. In the case of unit having a direct-connected exciter the losses to be included are:—I^2R losses in armature and field, core loss, load loss, friction and windage loss, rheostat loss, and total exciter losses. For a unit having separate excitation the exciter losses, rheostat loss and field I^2R loss should be omitted. Q.G.

1744—RESISTANCES IN SERIES MULTIPLE —Please show us how to calculate the amount of current in the different resistance coils in Fig. (a). G.H.S. (PA.)

This is the familiar problem of the Wheatstone Bridge, shown in a more familiar form in Fig. (b). Let *U*, *W*, *X*, *Y* and *Z* represent the currents in the respective coils. Then multiplying these



FIGS. 1744(a) and (b)

currents by the resistance values, equations (1), (2) and (3) are obtained, which represent the potential drops through the circuits on an assumption that current flowing from left to right

in Fig. (a) is positive. The direction of current in X is unknown, but the algebraic sign for its value in the solution will give the direction of current. From the law that the sum of all currents flowing towards a given point must equal zero, equations (4) and (5) are obtained. Having five simultaneous equations with five unknowns the solution is obvious.

$$
\begin{aligned}
4W + 2X + 3Y &= 100 \quad (1)\\
U + 3Y &= 100 \quad (2)\\
4W + 5Z &= 100 \quad (3)\\
U + X - Y &= 0 \quad (4)\\
W - X - Z &= 0 \quad (5)
\end{aligned}
$$

J.B.G.

1745—TESTING POWER FACTOR METER—Is it possible to test correctly a three-phase power-factor meter with the connections shown in Fig. (a) using a three-phase source of supply? The potential leads of the meter are connected across one phase and a non-inductive resistance is connected in each of the three-phases to supply current to the current coils. With all the circuits intact as in Fig. (a) will the meter indicate unity power-factor? I tried the above method but failed to get results, applying the red line and rotation checks. G.E.H. (OHIO)

A test can be obtained as shown in Fig. (a). However, the tester must consider that there is some impedance caused by the resistors in the circuit. The reactive factor of the resistors, unless predetermined, will have to be corrected for, when reading the instrument, to obtain a reading of unity power-factor. The instrument, when

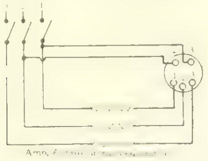


FIG. 1745(a)

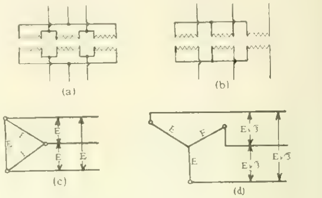
properly connected in phase sequence, and in phase relation with the voltage coil, should give a reading of unity power-factor when the currents in all three phases are the same. There must be no inductance in the circuit such as resistance tubes or impedance coils. In running experimental tests at the laboratory lamps are generally used as the resistance to balance the current side, and all possibilities of reactance in the circuit is avoided. The power-factor may be changed by means of a phase shifting transformer, or a synchronous device of some sort. H.P.S.

1746—REVERSAL OF EXCITER VOLTAGE—Two turbine-driven alternators of 2200 volts, 500 kw capacity, with direct-connected exciters are operating in parallel. The exciters are commutating-pole, compound wound with the usual equalizer connection. They are connected in parallel and are under Tirril regulator control. One exciter overcomes the other apparently and it becomes motorized. The generators drop their load but very soon pick it up again, but with both exciters reversed. Is it possible for one exciter to reverse the other (where the usual equalizer connection is used) and why, after the alternators have dropped their load and picked it up again, are both exciters reversed? E.M. (N.Y.)

With an exciter system in proper adjustment, it is practically impossible for a reversal of polarity to occur. If it does happen, the cause is likely to be found in some abnormal condition. Generally, such reversal results from a demagnetizing action of the exciter load current. When a surge, for instance, causes the regulator to diminish the exciter voltage to a low value momentarily, the exciter load current is not reduced much on account of the inductance of the alternator field, and the demagnetizing effect may overpower the weak shunt field, thereby reversing the polarity. This demagnetizing action would be present in an exciter having its brushes shifted forward and having little or no series field, or a reversed series. In a commutating-pole machine, where the brushes are set on the no load neutral, the armature would not produce a demagnetizing effect, but this effect could come from a reversed series winding. The motoring of one exciter by the other would not be expected to cause polarity reversal. If it is the cause, some unusual and unlooked-for combination of circumstances must exist. Stable parallel operation requires that each machine have a tendency to shirk its load, that is, an increase of the load on one exciter should be followed by a reduction in the voltage of that exciter with a consequent tendency to drop its load. A relatively high internal drop, a drop in speed with increasing load, a bucking series (connected inside the equalizer), and a forward brush lead, all add to this tendency to shirk. This tendency is lessened or removed if an unbalancing of the load between the two machines is followed by an appreciable magnetizing effect in the one taking more than its share of the load, and the reverse in the other. This is not liable to occur if the equalizer resistance is very low, and there is a reasonable degree of saturation in the magnetic circuits. In the present case, these stabilizing influences would be weak, or absent, so a comparatively slight disturbance may cause considerable inequality in the load division, and may result in a circulation of current between the two machines. The parallel operation could be made much more reliable by the use of a light bucking series winding, connected inside of the equalizer, say between the equalizer and the commutating-pole winding;—or by reversing the present series winding and doing away with the equalizer. This bucking effect should be quite small, or else polarity reversal may occur in the way suggested above; and it must be made certain that the shunt field winding has sufficient capacity to carry the increased ampere-turns required from it. With more complete data at hand, probably a more satisfactory explanation of the phenomenon could be offered. F.L.M.

1747—THREE-PHASE TRANSFORMATION—Three single-phase transformers connected delta-delta deliver 3000 k.v.a. If these same transformers are connected star-star using the same coil taps as for delta-delta, will they deliver the same voltage and k.v.a. at the same temperature? H.R.K. (CAL.)

When the method of connecting the transformers is changed from delta to star, the line voltage should be increased 73 percent as shown by the vector diagrams. If the voltage is not increased for the star connection, the



FIGS. 1747(a) to (d)

output (assuming the same current in the windings) will be only 58 percent of that for delta connection. The iron loss will, however, be lower. W.M.M.

1748—REVERSAL OF COMMUTATING-POLE GENERATOR—Please explain the action of a commutating-pole generator when it becomes reversed with a very small load, (say one-third full load); and also what is the most usual cause of reversal. Is it caused by the increased amperage through the demagnetizing turns on a short-circuit overpowering the field of a dynamo, which would become weaker owing to the drop in voltage of the machine (not on a compound dynamo with cumulative winding)? G.L.K. (ALBERTA)

Any direct-current generator connected to build up with one field polarity, will also build up with the opposite field polarity without any change in the connections of the field and armature circuits. Hence, in seeking the reason for an accidental reversal of polarity, one should look for some action which may result in a reversal of the residual magnetism. A short-circuit is liable to cause a reversal of polarity if the load current has a resultant tendency to demagnetize the field. This condition occurs in non-commutating pole generators, having a forward brush shift, and a weak series field or none at all. The machine voltage falls rapidly on short-circuit, but due to the inductance of the circuit, some current is still flowing when the field flux has been reduced to residual value, and the demagnetizing effect may be sufficient to reverse the residual magnetism. A similar action may occur with a compound generator on a fluctuating voltage circuit, such as a trolley line. A sudden increase in line voltage will reverse the current in the machine. The resultant demagnetizing effect of the series winding weakens the field and, therefore, lowers the generated voltage still further, the action being cumulative. This may result in the field flux being wiped out or even reversed, before the breaker opens. Other possible causes of reversal are the following:—Defective insulation, which permits current from other circuits to leak through the field coil; lightning; accidental contact of machine circuit with outside high potential lines. When a machine has been idle for a long time, stray fields from neighboring machines may reverse the residual magnetism. F.L.M.

CORRECTION

The second line in question No. 1700, Feb. '10, should read "220 volt direct-current car meters."

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Benjamin G. Lamme

The highest honor in the gift of the American Institute of Electrical Engineers —the Edison Medal— has been conferred this year upon Benjamin G. Lamme, chief engineer of the Westinghouse Electric & Mfg. Company. Mr. Lamme's career as engineer and inventor is too well known to need detailed repetition here. He has so long occupied a place of great prominence in his profession and has been so signally honored at various times that his name is known and his engineering attainments are recognized among electrical engineers throughout the world as of the highest order.

The rapidly developing engineering profession is, however, receiving constant accessions of young men from our technical schools and, as Mr. Lamme's career is so striking an example of the possibilities for growth and attainment by young men in that profession, and he himself is so greatly interested in seeing young engineers of talent develop, a brief statement here of the personal history of this remarkable engineer may serve to stimulate and inspire young men working in this field.

Mr. Lamme was born on a farm near Springfield, Ohio, and received his first education in the country schools of that vicinity, later entering Ohio State University, from which he graduated as mechanical engineer with the class of 1888. The following year he entered the testing department of the Westinghouse Electric & Mfg. Company, soon taking up designing, with which he has been identified ever since. His conspicuous ability as a mathematician and his keen analytical mind, coupled with absolute reliability, and yet boldness in attainment, soon marked him for advancement and he rapidly progressed to the position of assistant chief engineer, and in 1903 to chief engineer of the Company, which position he has held since that time.

He has always been a leader in the development of many of the most important lines in the greatly complicated and widely extended field of electrical engineering. His original inventions—several of them epoch-making in their scope—are covered by more than one hundred and fifty patents. During Mr. Westinghouse' life, Mr. Lamme was constantly called upon by him for development and pioneer work in the electrical field and the confidence and trust thus placed in him were amply justified by the many remarkable inventions produced in both the alternating and direct-current fields.

In addition to his duties as chief engineer of the Westinghouse Electric & Mfg. Company, Mr. Lamme has for many years been chairman of a standing committee which passes on the character and value of all inventions brought to the attention of the Company. Furthermore, when at the beginning of the war the American Institute of Electrical Engineers were requested by the Secretary of the Navy to name two men of the highest engineering attainments as members of the Naval Consulting Board, then being formed, they chose Mr. Lamme as one of them from a membership of upwards of ten thousand, thus conferring upon him a most distinguished honor and giving him the highest rank as an engineer and inventor.

With all his honors and attainments, Mr. Lamme is modest almost to shyness, but has never failed to take a great interest in young engineers. He personally examines each year a large number of the young graduates from the various technical schools and colleges who are beginning their professional work with the Company and selects those who give evidence of ability to develop rapidly to form a class in higher engineering studies which he personally teaches, following these men in their work until they become fully developed. Many of the Company's most talented engineers can testify to the remarkable stimulus gained by their personal contact with Mr. Lamme.

His reading and knowledge are by no means confined to engineering subjects. His keen mind has worked in many fields of intellectual endeavor and given him a breadth of learning and information rarely found. He is courageous, resourceful and persistent in his work, courteous and considerate in his dealings with all and is held in the highest esteem by those who know him best.

E. M. HERR

The Edison Medal

In February, 1904, a fund was provided and a deed of gift creating the Edison Medal executed between twenty-three individuals and the New York Trust Company, such deed being amended in March, 1908, to include as one of the parties thereto the American Institute of Electrical Engineers, whereby it was provided, among other things, as follows:—

> "The Institute shall, through a Committee to be duly appointed and authorized by it and known as The Edison Medal Committee, cause a gold medal to be executed from said die, or according to said design and specifications, and shall award said medal to some one resident of the United States of America and its Dependencies, or of the

Dominion of Canada for "Meritorious Achievement" in Electrical Science or Electrical Engineering or the Electrical Arts, whenever in the judgment of said Committee a resident of either of said countries is properly deserving of such award; provided, nevertheless, the requisite funds have accrued from said investment to so be made by the Trust Company."

In compliance with the obligation assumed by it the American Institute of Electrical Engineers in May, 1909, approved a set of by-laws of The Edison Medal Committee creating the machinery and prescribing the method of procedure to be thereafter followed in awarding the Edison Medal. Since that time awards have been made as per the following list of names and for the accomplishments as set forth, it being the privilege and duty of The Edison Medal Committee both to make the award and to state with great care, as briefly as may be, the reasons for their action. The list of distinguished men who have been honored by these awards is the best testimony of the way in which this important matter has been handled by the Committee having it in charge:—

1909—Elihu Thomson—"For Meritorious Achievement in Electrical Science, Engineering and Arts, as exemplified in his contributions thereto during the past thirty years."

1910—Frank J. Sprague—"For Meritorious Achievement in Electrical Science, Engineering and Arts, as exemplified in his contributions thereto.

1911—George Westinghouse—"For Meritorious Achievement in Connection with the Development of the Alternating Current System for Light and Power".

1912—William Stanley—"For Meritorious Achievement in Invention and Development of Alternating Current Systems and Apparatus".

1913—Charles F. Brush—"For Meritorious Achievement in the Invention and Development of the Series Arc Lighting System".

1914—Alexander Graham Bell—"For Meritorious Achievement in the Invention of the Telephone".

1916—Nikola Tesla—"For Meritorious Achievement in his early original work in Polyphase and High-frequency Electrical Currents".

1917—John J. Carty—"For his work in the Science and Art of Telephone Engineering".

1918—Benjamin G. Lamme—"For Invention and Development of Electrical Machinery".

Calvert Townley

European Switchboard Practice

The article on "European High-Voltage Switchgear" in this issue brings out many interesting points of difference between European and American practice. This is especially noticeable in the British designs, where government regulation has required much greater precaution in completely enclosing all live metal parts than has been customary either on the continent or in this country Aside from these features the essential differences are those produced by the radically different conditions under which the central stations were developed. The transmission of large blocks of power for long distances has been developed in this country to a much greater extent than in Europe, and this high-voltage practice, in which open wires and wide clearances are absolutely necessary, has influenced the designs for lower voltages in a way that has not been felt in the design of apparatus for which 20 000 volts was considered the upper limit.

American practice has also been to educate the workman with respect to the hazards of his profession, and then to depend largely on his intelligence to avoid accidents. Hence the safety features of American switchboards are largely limited to the omission of high-voltage contacts from the front of the switchboards, or in the case of the higher voltages, and especially in the larger stations, from the switchboard galleries; and to preventing the access of unauthorized persons to any part of the station equipment. The use of completely enclosed low-voltage switches, and of truck type and other enclosed conductor switchboard features has so far been largely limited to industrial applications and to switchboards, in substations or small plants in hotels, office buildings, etc. where highly skilled attendants are not always provided and where it is almost impossible to prevent the entrance of other employees. It is altogether possible that with the increasing difficulty of obtaining skilled attendants and the corresponding necessity for preventing the possibility of accidents resulting from carelessness, this type of switchboard, which has reached its highest present development in Great Britain, may become more common in this country.

At any rate this tendency in British practice is worthy of careful attention. The placing of a 20 000 volt, three-phase, high powered bus in a comparatively small cast-iron box, as is done in the Reyrolle switchgear, and the securing of absolute safety of inspection without exposed disconnecting switches, makes this arrangement very interesting to American engineers, accustomed to see concrete construction and bare copper busses and connections for such a voltage as 20 000.

The cellular construction of the circuit breaker compartments shown in the illustrations does not differ greatly from American switchboard practice. Many minor points of variation are, however, illustrated and especially the carrying of the gas vent from the top of the circuit breaker tank out through the cell doors is not seen in American practice. The lightning arrester installations are also interesting, as such large horn gaps are seldom installed indoors in this country, where the tendency is more and more towards locating all high-voltage equipment out doors.

The Achievements of Benjamin G. Lamme

Address of Presentation of the Edison Medal

B. A. Behrend

An address delivered on the occasion of the Presentation of the Edison medal to Mr. Lamme by the American Institute of Electrical Engineers in the Auditorium of the Engineering Societies Building, New York City, May 16, 1919.

THE DEVELOPMENT of the electrical industry in America is contemporaneous with the great industrial organization created by Mr. George Westinghouse and in the examination of its pioneers we are invariably arrested by the personality of Mr. Benjamin G. Lamme, whom it is our pleasure to honor tonight as the recipient of the Edison Medal. It is interesting to note that the medalist has just completed thirty years of service with the Westinghouse Company. There is something intensely significant in this fact. During these thirty years there have risen and there have vanished, like the colors in a kaleidoscope, many able and brilliant men who were connected with the Westinghouse Company in one capacity or another. Steadfast, patient and strong, there has remained the personality of Mr. Lamme to grow stronger with the years, so as finally to embody in himself, as it were, the thoughts of the engineering staff. I must confess that I have always enjoyed Mr. Lamme's versatile personality and that, in this sense, I may perhaps be accused of hero worship. Let the subject matter be one of engineering, one of politics, of the engaging problems of the day or of his favorite subject of archeology, his wholesome, sound sense and penetrative, subtle intellect will always impress his listeners. In point of illustration, here are a few pithy sentences taken at random from some of Mr. Lamme's writings. "A brilliant mind with little persistency back of it will usually accomplish less than a much less brilliant mind backed by great persistency."—"It is on account of specialization that it is so important that the young engineer of today obtain a broad knowledge of the fundamentals of his chosen line of engineering."—"Such a course of advanced training would attract a great many students regardless of the fact that the training would be of little or no use to them."

Endowed with a most unusual memory, and a facility for mental calculation to a point of efficiency which makes him spurn the ubiquitous slide rule, he combines an imaginative faculty of a most curious order. Passionately fond of every variety of intricate puzzles, some of which he invented himself, devoted to reading imaginative stories and tales of which he has collected a large number in his library, he is forever dissecting and analyzing the problems which come within his scope.

After this introduction to the medalist's personality, let me take you in mind to the fertile farm-land of Southern Ohio. There, by the Valley Pike, in Clarke County, between Dayton and Springfield, about two score and ten years ago, Benjamin Garver Lamme was born. The life on that farm gave him the rugged, constitution without which even his great talents would not have carried him through. "The personal fly-wheel," as he calls it, has often served him in good stead. Though extremely fond of squirrel-hunting, it is to be assumed that our young friend, Benjamin, must have liked other things better than farming. The early morning hours in 1887 and 1888, we are told, were often spent in poring over the pages of Sylvanus P. Thompson's "Dynamo-Electric Machinery." Ohio State University, the cradle of a group of talented men,—Sabine, Storer, Feicht, Skinner, Scott, Mershon—was also Mr. Lamme's Alma Mater. We see him interested in everything, the coach of the men of lesser gifts, and graduating eventually as mechanical engineer. After working on the flow of air and gas in pipes for the professor of geology, he applied for a position to Mr. Westinghouse, who had then just organized the Philadelphia Company for the development and exploitation of the wells of natural gas, and thus secured a "job" in Pittsburgh. After a few months,

his employer, Mr. T. A. Gillespie, recommended him to the Electric Company, where we find him in 1889 in the testing department under Mr. Albert Schmid. The conscientious apprentice was instructed to polish the brass on an 1100 volt alternator and he showed his thoroughness in omitting no brass parts, not even the current-carrying brushes. To some unknown, fortunate circumstances we evidently owe the fact of his survival. With oil can in hand, scrupulously watching the bearings of the machines entrusted to his charge, Benjamin Lamme is a familiar sight in the memory of his early associates.

Soon he became foreman of the testing department, and within a year his mind began to turn to inventions. From 1889, in increasing numbers from year to year, he obtained patents, reaching the rate of ten a year in 1898. Then we note a slight decline, only to attain a rate of sixteen patent applications a year in 1904. He has obtained at the present time the surprising total of 153.

The earlier activity was associated with the development of the rotary converter, the later with that of the single-phase system. It is interesting here to compare the medalist's own estimate of his connection with these developments, and I quote:—

> "A year or so ago, in discussing the subject concerning which you have just written me, you mentioned that the single-phase railway motor or system is the one by which I was best known. This appears to be true, but it has seemed to me unfortunate that it should be so, as I do not consider it as the one thing for which I should have the most credit.
>
> As you may know, the rotary converter, as it stands today, covering almost the entire field of railway business, has reached its commanding position very greatly through my efforts. In the early days of the rotary converter, beginning in 1893, this device was looked upon with a great deal of doubt. In the early days of commercial application, I had to fight the battle for the converter pretty much by myself. That I made a successful fight is indicated by the fact that, in the period between 1898 and 1902, the Westinghouse Company was probably furnishing 75 percent of all the rotary converters then built and this business was becoming of very considerably proportions."

That he was early in this field is indicated by the fact that nearly all the patents taken out on rotary converters in those days were in his name. Many of the modern necessities in rotary converters were originated and first used by him in such apparatus. I may cite the damper as one of these examples. While it developed afterwards that Leblanc had a broad patent on the damper, yet at the time that Mr. Lamme developed and used it on the rotary converter, he was not aware of Leblanc's patent, and he may claim the credit of being the first to use such dampers to overcome fundamental rotary converter difficulties. The entire problem of hunting, which at one time threatened to put the rotary converter in the discard, was overcome by his early work. This, however, was only an incident in the development. When it came to 60 cycle converters, he stood practically alone for many years, and his work has been instrumental in giving these machines the final high position which they now hold in the industry.

He has always led in the battle for higher speeds, resulting in smaller, cheaper and more efficient converters. Therefore, considering all these things, I believe we may state that there is more credit due him than to any other one person for the present leading position which the rotary converter holds in the electrical field. Yet to consider this as a larger and more important work than the single-phase system is, in my opinion, one of those strange vagaries of judgment often affecting us in connection with our own work.

Again, he can claim to have been the leader in the direct-current railway motor development, as far as fixing types of apparatus is concerned. His earliest single-reduction railway motor, the Westinghouse No. 3, or rather its experimental predecessor, contained most of the fundamental features found in the present universal type of railway motor. This early motor was of approximately cylindrical type with four internal radial poles and was of the ironclad, or partially-enclosed type. This was a most radical departure from former constructions and at once overcame many of the earlier difficulties. The armature of the experimental machine, and of all later machines, was of the slotted type, with open slots and with machine-wound coils. At this time this was the only railway motor of the kind, and these features have since been universally adopted. In addition, the two-circuit or series type of armature winding was first developed and used on this motor and this type of winding is now in universal use for railway motors and almost all other multipolar machines of small and moderate size. Many other features of this early construction are still retained in modern railway motors. Therefore, he may claim credit for having established the present universal type of railway motor.

Considering the direct-current generator, and particularly the railway generator, while there were more workers in this field, yet I feel that he should have much credit for establishing certain fundamental features in the early machines, which are retained or considered necessities even at the present time. He was the first to bring out the railway generator with slotted armature, both for the partially closed and the open slots. The form-wound armature coil of copper strap on edge, used with open slot direct-current armatures, was worked out by him. These earliest machines had a very high saturation in the armature teeth, in order to give stability and prevent distortion. This is also modern practice. When the limits of the two-circuit winding were reached and multiple windings began to be used extensively, he devised in America the polyphase equalizing connections which are now considered a necessity in such machines. He also used the fractional pitch or chorded armature winding for direct-current machines, for the purpose of reducing the commutating constants, thus improving the range of operation without shifting the brushes. Therefore, in this line of apparatus, many of his original features of

construction are still in use after twenty or twenty-five years of development.

In his work on rotary converters, railway motors, and direct-current generators, it can surely be said that he has had much to do with solving the problem of commutation, in the sense of determining the conditions which affect commutation and taking advantage of those characteristics and features which improve commutating conditions. In his papers on the theory of commutation, which were published by the Institute some years ago, I believe that he went considerably further into the subject than any one else had done up to that time. Quite a number of manufacturing engineers have taken up the method given in this paper and adopted it as a basis for their work, with very considerable benefits in the way of improved accuracy in their calculations, and increased outputs from a given amount of material. This paper, however, was more or less a result of all his previous experience and investigation on the subject, and it is simply an indication of how far he had gone into the general subject of commutation.

While he was not among the first to develop induction motors, yet he was among the first to produce commercial induction motors, as his work began in the latter part of 1892. His leading work in this line was the recognition of the principles upon which the Westinghouse type "C" motor was brought out. Up to that time (about 1895) it was generally held that the cage-wound motor was necessarily one with a small starting torque and that, in order to give high starting torque, it had to be made with a high secondary resistance and, therefore, high slip at normal load conditions. From his analysis of the design characteristics of the motor, he drew the conclusion that it was not a question of high secondary resistance and high slip, but one of the ratio of the reactance of the motor to the secondary resistance; that is, by reducing the reactance instead of solely increasing the secondary resistance, high starting torque could be obtained, but at the expense of high starting input. He then proposed to design such motors with relatively much lower reactance than had hitherto been the case, and thus obtained starting torques of several times the normal running torque, and which he reduced by the use of lower starting voltages by autotransformers or autostarters. He worked up many experimental motors and proved this principle and also, through his method of analysis, determined how to reduce the reactance of the motor by using widely distributed windings, and by giving careful attention to the elements of the magnetic circuit, without materially increasing its size and cost. The results, put in practice, were the line of type "C" motors. This radical type took the market and forced the situation to such an extent that it gave great impetus to the industrial application of polyphase currents.

In the task of entering intimately into Mr. Lamme's work, we are aided fortunately by the possession of historical sketches, from his own pen, of the direct-current railway motor, the alternating-current generator, and the direct-current generator. To these we must refer the readers who wish to follow his work in the evolution of electrical machinery.* The universal type of single-reduction railway motor owes to him a great debt, and the rotary converter, especially the 60 cycle types, are largely his creation. These conceptions found their early and practical expression in the 1500 kw rotary converters and the 5000 kw flywheel generators of the Interborough Rapid Transit Company's Manhattan Station. The electrical dimensions of the first vertical generators of the Cataract Construction Company were Mr. Lamme's part in the great power development at Niagara Falls, and it must be gratifying to him that he was thus connected with this interesting historical landmark in electric power transmission.

There are many other fields in which he has had a hand. In the single-phase railway system, which he created, he deserves much credit for the fact that he successfully commutated alternating currents, after it had been quite definitely accepted as being one of the impracticable or impossible things. Of course, the development of the single-phase railway system was a direct result of the successful development of a commutating alternating-current motor. I think Mr. Lamme's leadership in the single-phase railway field has followed logically from his work in the transformation of Nikola Tesla's great creative ideas into commercial form. Mr. Lamme's principal, Mr. George Westinghouse, staunchly believed in the universal application of alternating currents and, as the difficulty of collecting alternating currents from two trolleys precluded, in the minds of the railroad men, the use of the polyphase system for railway work, Mr. Westinghouse and Mr. Lamme were led logically to the hope of developing a single-phase motor and adapting it to the railway field. This Mr. Lamme succeeded in doing originally by boldly adopting a low frequency of sixteen cycles and designing for it a series-wound alternating-current commutator motor. A little later, however, he discarded this frequency and developed a 25-cycle single-phase motor, in which the use of resistance leads, reducing the transformer current in the short-circuited coils, is one of the salient elements. Thus resulted the 25 cycle single-phase railway motor so widely adopted in Europe and to a degree in America. Surely, the electrification of the New York, New Haven & Hartford Railway will always be associated with Mr. Lamme's name. No more bitter debates were ever heard on the floor of this Institute than those on the relative merits of the single-phase and the direct-current systems. Yet even the most re-

*Published in THE ELECTRIC JOURNAL as follows:—"The Alternating-Current Generator in America", Vol. XI, Feb. '14, p. 73; Mar. '14, p. 120; Apr. '14, p. 221. "The Development of the Direct-Current Generator in America", Vol. XII, Feb. '15, p. 65; Mar. '15, p. 115; Apr. '15, p. 164; May '15, p. 212. "The Development of the Street Railway Motor in America", Vol. XV, Oct. '18, p. 408; Nov. '18, p. 454.

lentless opponents of the single-phase system must admit in justice that Mr. Lamme's conception of railroad electrification stood for the use of a high voltage working conductor, as he recognized that the 600-volt third-rail system imposed too great a burden upon extensive railroad electrification. In setting himself the task of producing a motor which, while possessing the characteristics of the series direct-current motor, would operate on any trolley potential, however high, and in successfully solving this problem, and fearlessly applying it to the New Haven system with 11 000 volts on the working conductor, Mr. Lamme gave an impetus to the entire field of railroad electrification which will always be a milestone in the electrical industry, and in the field of transportation. Suffice it to say that the feverish activity in the development of rival systems, the general adoption of the overhead trolley, the doubling and quadrupling of the direct-current voltage thereon, have been due to Mr. Lamme's bold creative work. From it has sprung a new life, a true "instauratio magna", in the electric transportation system the world over.

Fifteen years have passed; both systems are still in use almost literally side by side, neither having succeeded in displacing the other, and prophecy would be idle. Be the fate of the single-phase system what it may, the medalist will always be remembered as its successful pioneer.

With the advent of the steam turbine, Mr. Lamme turned his universal genius to the development of a type of turboalternator known as the "parallel-slot" type. It is one of the most ingenious designs which have been developed in this difficult art. While the types which he designed have not been enduring, yet they served as pace makers in the race towards the present high speeds and high economies resulting from such speeds. Therefore, I feel that he accomplished very considerable results in this field. Bold and venturesome, he urged increased speeds, ever higher and higher, and tenaciously adhered to this policy. Great credit is due him for this fearless advocacy.

Two years ago, when the Secretary of the United States Navy established the Naval Consulting Board, the Directors of the Am. Inst. of Electrical Engineers were requested to nominate, and to recommend to the Secretary of the Navy, two members of their great body who, in their opinion, would best fulfil the requirements to be made of that newly created Board. It was a great pleasure for the present speaker that he then had an opportunity to commend Mr. Lamme's name. It is yet too early to appraise the good work done by Mr. Lamme on the Naval Consulting Board in his capacity as Chairman of the Inventions Committee.

As an "engineer-teacher", he has had remarkable success. Storer, Renshaw, Hanker, Wilson, Hague, Laffoon, and others sat across the desk from him and profited by his sound sense and versatile intellect. The methods of calculation of electrical machinery in use at the Westinghouse works were inaugurated by him and still bear the marks of his individuality.

Men like Benjamin Lamme are, as it were, the integrated personalities of an organization. They figuratively represent the aggregate. Such men are rare, indeed. When they appear among us, a dynamic equilibrium, so to speak, of intellect, shrewd common sense, and exceptional health, they present the picture of success. Somehow, in the twenty-two years I have known Benjamin Lamme, he has always called to mind the figure of another great American, of bygone years, who also worked in the field of electricity. In appearance even, but surely in his astute, sententious wisdom, I am reminded of Benjamin Franklin, more than a mere namesake.

Mr. Lamme, it is a great pleasure to be here tonight and to pay you my homage in these words.

Response to Address of Presentation

BENJAMIN G. LAMME

MR. PRESIDENT and Mr. Chairman of the Edison Medal Committee, Ladies and Gentlemen:—My appreciation of the honor conferred on me in the award of the Edison Medal cannot readily be expressed. Looking back upon my earliest days in the electrical field, when the forces with which I was allied were in bitter rivalry with those at whose head was the man whose name this Medal bears, it is hard to conceive what a tremendous change has taken place in so few years. Any one in the enemy's camp was then, of necessity, an enemy himself. Now the rivalries in the electrical industry are between organizations, the members of which may be the best of friends. I wish to say right here that much of this change in attitude may be credited to the "get-together" efforts of this Institute, and one of the strongest evidences of this spirit is in the character of the technical papers and discussions at its meetings, compared with those of some twenty years ago.

It is, of course, a very great pleasure to hear the kind things which Mr. Behrend has had to say about myself and my work, but I feel that he has taken this occasion to flatter me unduly, knowing that under the circumstances I could only sit and listen to him. Some of his viewpoints, I assure you, are as new and novel to me as to you.

Several of my kind friends have told me that I am expected to relate a number of incidents of human interest regarding discoveries and developments with which I have been connected. Accordingly, I have gone over about everything in my thirty years of active work in the electrical field, looking for "high spots", so to speak, or matters outside of mere technical details. However, there appears to be but little of popular inter-

est to be found. In one way, my business life has been somewhat different from the careers of several others who have received the Medal, in that they have been "free lances", so to speak, whereas I have been a working part of a large engineering and manufacturing organization where results are not due to the efforts of one individual but to the co-operation of many. Consequently, there has been no one particular line of development upon which I specialized; for, with my associates, I have had to take up almost anything as it came along. Apparently, the members of the Medal Committee were somewhat puzzled by this situation for it may be noted that the award was made on such very general grounds as, "Invention and Development of Electrical Machinery".

Most people are particularly interested in accounts of wonderful inventions or discoveries; and the cold-blooded methods of the engineer in driving through all obstacles to a desired result do not contain for them any especial elements of romance or excitement. They do not recognize that the work of the engineer carries responsibilities, which ofttimes is not the case with the inventor; moreover, they are not aware that the engineer in the manufacturing field, when he once embarks on a program, is obliged to see it through to the end, and that he must stand or fall by his results. To state it very briefly, the experimental attracts more attention than the analytical. The modern engineer, especially in the electrical field is largely an analytical man and his adventures in analysis do not appeal to the popular taste. The earlier work in any engineering art is always of the "cut and try" sort—necessarily so—for the preliminary data required for analysis must be obtained by experiment. As the laws, principles and facts are gradually uncovered, those men with an analytical turn of mind begin to formulate the available facts, build up theories and, by their analyses, derive other related facts. They see, ofttimes far ahead, most useful results which appear possible of attainment, and they turn their full energies toward the successful accomplishment of such results. Such men are generally designated as engineers, rather than experimentalists or inventors; and the boldness of their methods and the directness with which they drive through to desired results should be just as exciting and spectacular as many of the brilliant discoveries, if only their methods of attack were within the popular perception.

In an industrial organization, the engineering developments are almost always the result of co-operation of many trained minds and, in consequence, it is difficult to give any one man a large share of the credit. The work of such an organization more resembles that of an army than of an individual. One man alone, in most cases, cannot accomplish the desired results for, quite often, the undertakings are so various in their elements that the combined efforts of many minds are needed for success. In such an organization, an individual may appear to have less opportunity to stand out prominently, in comparison with others, than where he is working more or less alone; yet, at the same time, it must be borne in mind that each engineer has the knowledge and experience of his co-workers, upon which to build, and in this way, he can accomplish results which would be impossible through his own individual capacity. Many of the developments now being carried through in the engineering field so far exceed any individual capabilities that only the united efforts of many brilliant minds can attain success; and he who does his part can well take pride in the greater accomplishment, even if there may be less personal glory in it. Furthermore, there is a sense of responsibility in such work which has a strong appeal, for when a great engineering and industrial problem is once in motion, it must be carried through to success or failure, and there can be no dallying on the way, no stopping or turning aside, until the desired result is attained.

Without the backing of immense resources in capital, equipment and experience, and without the greatest co-operation of many analytical minds, there could have been no such an accomplishment as the modern high-speed, huge-capacity turbogenerator sets. In such a development, limitation after limitation, based upon previous experience, has been set aside. Each step in advance usually has offended some proven experience of practice. And, with each step, it usually was said, "This is the last," but the data from each one pointed a way to the next—the end is not yet.

As another illustration, in the railway field the steam locomotive has been a long development, requiring the experience of years. But where the electrical designers have undertaken to supplant the steam locomotive, under new and most difficult conditions, they have attacked the problem boldly and confidently, as instanced by such leading examples as the New York Central, New Haven, Pennsylvania, Norfolk & Western and the Milwaukee, all embodying radically different types of locomotives and all successfully accomplishing the desired results.

In reviewing my work to find something which might appeal to the popular fancy, it appears that in any development out of the ordinary which I could describe there is no big discovery in the usual sense; in fact, in all of my endeavors, apparently few of the results can be credited to much more than constructive analysis, assisted by calculation and, in consequence, any description of such work would be of interest to only a few. Nevertheless, I will tell the story of one development in which I have always had pride which, however, is

but little known because of lack of spectacular elements. This concerns the single-reduction-gear railway motor development, back in the summer of 1890, just a little over a year after I entered the electrical business, and before the company with which I am connected had any organized engineering department.

Leading up to this, a little personal history is required. On May 1st, 1889, by an accidental circumstance, I was enabled to enter the employ of the Westinghouse Company at Pittsburgh, where I was placed in the test room by Mr. Albert Schmid, then shop superintendent. My college training had covered a purely mechanical engineering course, but I was more or less interested in electrical machinery from the construction standpoint. Some months after I had entered the company, Mr. Schmid spoke to me very pleasantly one evening in the test room, and a little later I received a message to call at his office the next morning. There, he said he understood that I had some experience at "figuring things." I said that I had done some calculating on the flow of natural gases in long pipe lines for the State Geologist of Ohio, but had never figured on anything electrical. He said that made no difference as long as I could figure, and he wanted to try me on something. He then explained that he believed electrical machinery could be calculated, just as well as other kinds, but that other people did not agree with him. He had tried several men on such work but was not satisfied with the results. Someone had told him that there was a young fellow in the test room who could figure, and so he had made inquiries concerning me, and he wanted to try me out. I agreed, of course, to make the attempt and he then showed me a little pamphlet, written by an Englishman, in which there were certain crude methods of calculation worked out. He reviewed this very painstakingly with me and then asked me what I thought. I told him that I would like to try my hand at such calculation and so I was set to work on it, using my spare time between tests, to see what I could do in the way of checking up the saturation curves on our existing alternating-current machines. I soon found that I could get reasonably close approximations, in so far as our magnetic and electric data at that time would permit. Mr. Schmid was a mechanical engineer by training but he was intensely interested in these electrical calculations and gave me much encouragement. This was really the beginning of the calculation of electrical machinery in the Westinghouse Company.

In the latter part of 1889, Mr. Westinghouse was planning to go into the railway equipment business and he asked Mr. Schmid to have a study made of the subject. Mr. Schmid then told me to get busy and first investigate the existing systems and then see what I could do toward calculating a suitable railway motor. In January, 1890, I prepared specifications, from calculations, for a double-reduction railway motor very much along the general lines of the then existing types. This was the first machine which the Westinghouse Company produced entirely from calculations, and when built, it was sufficiently close to the specifications to be put on the market as a commercial machine. This was known as the No. 1 Westinghouse double-reduction motor. I am telling this because it leads up to the development of the single-reduction-gear motor.

In August, 1890, during a strike at the Company's plant, the test room was shut down and, to keep busy, I took up the problem of the electrical design of a single-reduction-gear motor for railway work. My short experience with the double-reduction motor in service had convinced me that this type, with its exposed armature and field windings, and two sets of gears, could not persist very long. Consequently the production of a new type of motor to overcome these difficulties was a very live problem at that time. My little practice in calculation doubtless gave me undue confidence in tackling this new problem, so I deliberately undertook to analyze its possibilities. Right at the start, my rough figures indicated that such a machine should be of a four-pole type in order to keep down the weight. With this as a starting point, I naturally turned toward the Westinghouse alternator type of field construction with its internal, symmetrically spaced poles. This appealed to me as presenting several great advantages for railway motor construction, for the external yoke of the machine naturally formed an ironclad protection for the motor as a whole, and it would be a very easy matter to house the lower half to protect it against damage from below. So far, so good, but when it came to the armature, I was fairly "stumped" for awhile. I first worked out a surface-wound armature, such as was common practice on railway motors at that time, but found at once that, due to the large iron-to-iron gap, the construction was practically prohibitive with four poles. This apparently brought me up against a blank wall. However, various other possibilities were then considered, among them the "slotted" type of armature, such as was being used on small capacity machines by the United States Company, then a subsidiary of the Westinghouse. This type of armature was considered practicable up to a few horse-power, but no one imagined it to be at all suitable for anything as large as a railway motor. However, I was strictly "up against it" and was grasping at straws, and so this slotted construction was given serious consideration. To my great pleasure, the first figures indicated that, from the magnetic standpoint, the slotted construction allowed a quite low speed motor of proportions permissible for a street car equipment. However, when it was attempted to work out the armature winding itself, another most serious difficulty appeared. Up to this time, the one type of winding considered practicable for four-pole machines was what is now known as the "parallel" type, with four circuits, and requiring four brush arms unless all the commutator bars were cross-connected. This appeared to me to be impracticable for railway work, and we were faced by a most serious difficulty. However, I then spent several days attempting to work

out some form of four-pole armature winding which inherently required only two brush arms, and with only two circuits in the armature instead of four. After two or three days' work, I found a winding which gave exactly what was desired and this was used in the construction of the first motors of the new type.

When I had gotten this far, I took my crude results to Mr. Schmid. He received them very enthusiastically and immediately had drawings started, the company's draughting room being directly under his charge. He incorporated a number of important features, principally of a mechanical nature, and arranged to have two machines rushed through for a trial equipment. To avoid attracting attention, the new machine was not called a street railway motor, but was designated a "mining motor"; and as no one knew what a mining motor should look like, no curiosity was aroused and but few questions were asked.

After the work had well progressed, it dawned upon Mr. Schmid that an entirely new type of armature winding was specified for this machine, in addition to all of the other radical features. When taken to task, I explained to him why it had been used, and insisted that it was theoretically correct, and that there was no other known way of accomplishing the desired result. As the work was so far progressed, he accepted my arguments. Also, in these first two machines, 1/32 inch mica was used between the commutator bars, whereas the usual practice on railway motors at that time was 1/16 to 1/8 inch mica. This radical departure, it developed afterwards, was one of the exceedingly fortunate things we did in this machine.

As originally planned, the two new slotted armatures were to be hand wound, as hand windings were standard practice at that time. Shortly after this was tried, I became thoroughly convinced that the hand winding for the slotted type railway motor could not be entirely successful, so I then proposed machine-wound coils, insulated before being put on the core. My associates and myself then spent two or three weeks in attempting to produce machine-wound coils of such shape that they could be placed symmetrically all around the armature core, as developed in later practice, and we very nearly succeeded in this. It appeared later that, with certain minor modifications in the shape of our coils, we would have obtained the symmetrical winding. However, as the work was in a great rush, it was finally decided to put on machine-wound coils, the ends of which would be bent into position after placing on the core. The foreman of our transformer winding department and myself, neither of us with any previous experience as armature winders, then put the machine wound coils on these two slotted armatures, both of which stood the shop tests and both were sent out on the first car equipment. Even at that time, I considered this a most conclusive proof of the superiority of machine wound coils, in that two inexperienced men could make a success of this winding in their first attempts.

In the latter part of 1890, these two machines were put on test and checked quite closely with the calculations, and what was more important, the slotted armatures commutated better than we expected and the new type of armature proved to be thoroughly satisfactory. This motor, in the spring of 1891, was put on the market as the Westinghouse No. 3, and so quickly did it take, that the entire stock of double-reduction motors on hand, some two or three hundred in number, had to be scrapped, as they could not be sold.

This single-reduction-gear motor should be looked upon as the direct "ancestor" of the modern universally adopted type of railway motor. In fact, the present street railway motor contains practically all of the main features found in this early railway motor, but with certain additions and improvements. Moreover, the new type of armature winding, which later became known as the "two-circuit" or "series" winding is now used the world over. The pride which I feel in my part of this early development is not so much in the motor itself, as in the type. When it is considered that the life of most types of electrical machines does not average more than ten years, it may be seen that the initiation and development of a radically new type of railway motor twenty-nine years ago, which has since become the universal type, and as yet shows no signs of obsolescence, is something of which any one should have the right to hold pride.

This story illustrates fairly well the general nature of the engineering work in connection with the various lines of development which my associates and myself have followed. It should be obvious that such development, although sometimes revolutionary in character, is not in the nature of brilliant discovery, but is more like attempting to solve new and unusual problems in mathematics or mechanics.

In progressive manufacturing organizations, as a rule, there can be no particular "pets". When any new line of development holds forth broader and greater possibilities, often the old and accepted practice and constructions are turned down ruthlessly in order to replace them with something more promising. Many times I have assisted strenuously in "obsoleting" some of my own best work just to make way for something of greater promise. For instance, I spent a number of my best years in doing my part in the development of the direct-current engine-type generator, up to a point where it seemed to be perfection; but I made equally great efforts in the development of the 25 cycle rotary converter which was destined to supplant, in general, the direct-current engine-type generator as a source of direct-current; and still later I put equal efforts in forwarding the development of the 60 cycle rotary converter to supplant the 25 cycle machines for general power purposes. As a second instance of tearing down work in which I had a considerable share, I may cite the alternating-current engine-type generator which had reached its greatest magnificence in the huge Interborough machines in New York City, and which was

rendered obsolete as a type by the development of the high-capacity turbogenerator. And, as Mr. Behrend once aptly said, the pity of it is that the accumulated data and experience of years, in the development of the engine-type alternator were practically thrown away, in as far as the turboalternator development was concerned.

This dying out or replacement of old types affects one who has been close to them, very much like the departure of old friends; and often I look back on those old-timers with feelings of regret that the march of progress had to leave them behind.

So much for development. Now as to inventions; in my case, they could mostly be classed as *byproducts*, as someone has aptly put it. In an engineering and manufacturing organization, the first efforts of the engineers are expended in obtaining certain desirable results in the most successful manner. Usually, if a result is one not accomplished before, or is an improvement over existing practice, new and novel (and consequently patentable) ideas quite frequently are involved. The real engineer on this work usually does not set out to "invent something". If he does, too often he is unduly influenced toward setting aside, or rejecting, old and well-tried methods, in favor of something novel and, therefore, possibly patentable. Preferably, he should strive for the greatest success, without regard to novelty, and from this viewpoint his inventions may be looked upon as consequences rather than causes; or, briefly, they are byproducts. Quite a large percent of my so-called inventions were of the remedial class, that is, they were the results of attempts to correct difficulties. A few of them were the direct result of analysis and calculation. None of them were of a kind which would interest any but those familiar with technical details. Being byproducts, they do not represent wonderful discoveries, in the usual sense of the term, and, therefore, nothing further need be said about them.

From the standpoint of development and inventions, the past looms large, but how about the present and the future? In looking over the past history of electrical engineering, the engineer may be inclined to think that the golden age of development and invention is past, and that the future contains no corresponding promise of new and startling things. But I do not agree that this is so. The pioneering period may be over, but the true development age has possibly just begun. The work is growing more difficult year by year, as our accumulation of knowledge grows. We are working ahead of our data, just as we did twenty to thirty years ago. Exactness and responsibility are required to a much greater degree than in the past, for our undertakings are greater in degree. The wonderful advances in the earlier times did not seem so very wonderful while we were in the midst of them. In fact, at the time, many of them were simply hasty remedies for serious difficulties, which were accepted and adopted out of necessity. But similar situations of today are also having their remedies supplied, ofttimes requiring vastly more difficult engineering than in the past; and viewed from a twenty-year future, many of these also will loom large. It is all because we have no proper perspective of the present.

So the young engineer need not be discouraged. The fact that the work is growing more difficult year by year should be, in itself, a source of encouragement. It has been my good fortune to see, from the inside, the electrical machinery development from the cut-and-try stage, through the intermediate steps, to the highly analytical methods of today, and my experience indicates that a higher grade of engineer is required now than ever before. There was a time, many years ago, when I thought that the work would grow easier with greater knowledge, but I overlooked the fact that we would always attempt to work far ahead of our data and that, in consequence, the work itself would actually become increasingly difficult, as we undertake problems which we would never have dreamed of attempting in the past.

I have said that much of my work has been in association and co-operation with other engineers. One of the duties which I have assumed, possibly in part unconsciously, has been the training of the younger engineers who followed, as I was trained by those who preceded me. In looking over the list of the latter, the one name which stands out above all others is that of Mr. Albert Schmid, who started me on my engineering work with the Westinghouse Company. His initiative resulted, through my later efforts, in the development and establishment of methods of analysis and calculation which are used most extensively today throughout the Company's organization. A mechanical engineer by training, he held, as early as 1889, that electric machinery could be calculated with the same accuracy as other kinds of apparatus. In carrying out this belief, he gave me the greatest possible opportunities to prove out by actual trial my endeavors in calculation, and if the results were unsatisfactory, or were failures, he shouldered the responsibility, if successful, he gave due credit. In time of trouble, (and troubles were many in those days) he was ready with helpful suggestions, not destructive criticisms as is too often the case. Possibly the most pleasing thing I can say is that in my later work in training and dealing with younger engineers I have endeavored to treat them in line with his treatment of me in my early days.

There have been very many other associates in my thirty years, so many that individual mention cannot well be made. I have seen many of them grow from pupils to assistants and associates, and one of my greatest pleasures has been to see this growth. I have allowed no petty jealousies to interfere with their development, and I have always felt that as they grew so would I grow with them. I have aimed to instill in them fundamental ideas of engineering honesty and honor, square dealing and fair fighting, that there should be pride in accomplishment, and that true engineering means much more than merely making a living or obtaining an income;—that it means advancement of the art for the benefit of mankind.

European High-Voltage Switchgear

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THERE is a wide difference between British switchgear designs and those of Continental Europe. In Great Britain, with its numerous coal fields, well populated industrial areas and absence of water falls, transmission voltages over 15 000 to 20 000 are rarely needed. Only now are there under consideration enlarged linking-up schemes which will employ pressures of about 35 000 volts. On the Continent there are in operation some systems working at pressures up to 110 000 volts.

The majority of British switchboards are built on the cellular principle, of which the 6600 volt equipment shown in Figs. 1 and 2 may be taken as typical. The cells are usually constructed of brickwork, moulded stone or ferro-concrete, and the lay-outs commonly adopted conform to usual American practice for like voltages.

The main difference is in the care taken to enclose all live metal. Government regulations require that the greatest precautions be exercised to prevent accident, and even where separate high-voltage switch rooms exist, each individual compartment has a removable door which may be of sheet iron, expanded metal or asbestos lumber. The 11 000 volt oil switch cubicles on the London & North Western Railway Company's switchboard, Fig 3, show such protection admirably. The elaborate precautions which are required have naturally resulted in the evolution of special designs in which total enclosure and fool-proof interlocks are fully developed. Such gears fall into two classes, known as draw-out pillars and truck switchgear.

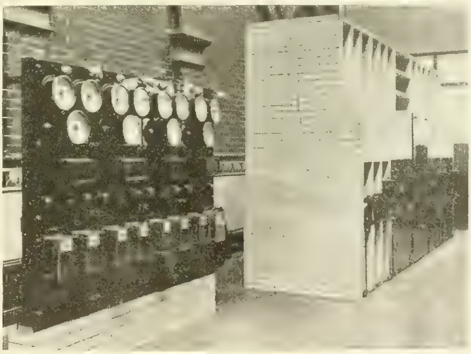

FIG. 1 GENERAL VIEW OF 6600 VOLT, 3 PHASE, 50 CYCLE, OPERATING BOARD AND HIGH-TENSION CUBICLES
At Stoke-on-Trent corporation substation.

DRAW-OUT PILLARS

The essential characteristic of draw-out switchgear is that the oil switch is movably mounted on suitable brackets and is fitted with plug contacts engaging with corresponding female contacts located on a fixed support. The general construction is evident from Fig. 4. This class of apparatus was designed primarily for colliery use, underground. Hence all live metal is enclosed in a stout cast iron case, such instruments as are required being located in the removable oil switch section, together with the automatic release coils and the series transformers. The fixed pillar carries the busbar sections and the cable potheads.

The general practice has been to limit the application of this apparatus to substation work on systems not exceeding 3300 volts. Messrs. A. Reyrolle & Co. have, however, carried the design much further and standardised draw-out pillar switchgear for use on systems up to 20 000 volts and for any plant capacity yet installed in England. The majority of the switching apparatus on the North East Coast Power systems is of this type.

In Figs. 5 and 6 are shown front and rear views of a typical Reyrolle equipment for 20 000 volts. From the front the appearance is much like an ordinary control switch board built into the wall. All the high-voltage gear is located close against the back of the wall, through which the oil switches are operated mechanically. The oil switch has been removed from the pillar seen in the foreground of the rear view, the switch itself standing on the switch carriage at the far end of the room. In the upper portion of the stationary structure, nearest the wall, are carried the busbars arranged in the horizontal plane. From the bus section projects the casing which carries and protects three plugging contacts, while immediately below are the corresponding plug contacts for the outgoing cable. Safety doors automatically cover these contacts whenever the oil switch is disconnected from them.

The switch body has rollers which run on the cantilever brackets and the latter are long enough to enable the switch portion to be withdrawn from the plug contacts and fully isolated for inspection. The busbars, series transformers and connections to the switch are all filled in solid with compound, and in this manner adequate insulation is secured while a minimum of space is occupied.

TRUCK TYPE SWITCHGEAR

Truck type switchgear is arranged on a similar principle to the draw-out pillar, of which design trucks were in fact the fore-runners. In general trucks have application in the higher voltage field which Messrs. Reyrolle alone fill with draw-out pillars.

A typical British Westinghouse Company's truck panel is illustrated in Fig. 7, which clearly shows the arrangement of apparatus adopted. The contacts on the movable truck are flexibly mounted, in such a manner as to compensate for quite large discrepancies in the setting of the fixed contacts on different panels. The truck is a more flexible unit than the pillar in that practically any combination of instruments can be mounted, and moreover special switches such as those used for split conductor protection may be used when necessary. Draw-out pillar type switchgear is practically unknown on the Continent, although the truck design actually originated in Germany some 12 or 15 years ago, and is to-day built in Germany and by Messrs. Magrini in Italy and Brown Boveri in Switzerland.

the front so as to form in the bottom of the cubicle a receptacle of sufficient size to hold all the oil, should a tank burst or leak. There is a drain in the bottom of the cubicle to conduct this oil to the outside of the building or to a special fireproof tank. In an alternative arrangement due to Messrs. Brown Boveri, the drain is replaced by a thick layer of coarse sand or gravel, which would act as a fire extinguisher. A sheet metal screen closes in the whole of the front of the oil tank compartment making it fireproof. The oil switches used on the Continent are often of very light construction, so that these precautions against bursting are in a measure justified. British switches and Continental switches intended for high voltages and big powers are now designed to withstand without mechanical damage the destructive ef-

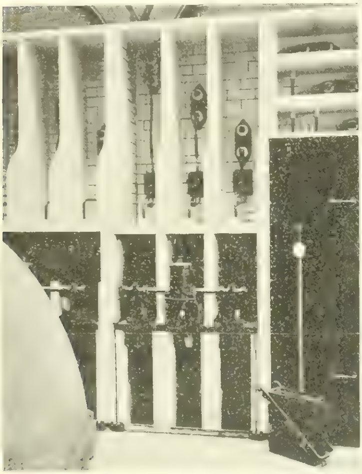

FIG. 2 FRONT VIEW OF HIGH-TENSION CUBICLES

Containing electrically operated oil switches, series transformers and isolating switches.

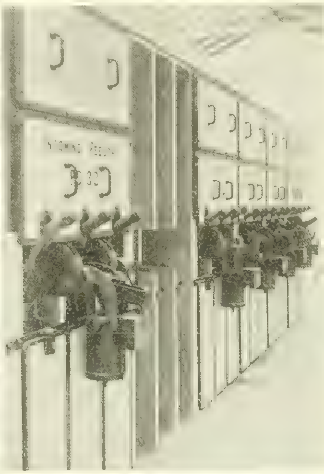

FIG. 3 FRONT VIEW OF HIGH-TENSION CUBICLES

Containing 11 000 volt, three-phase, electrically operated oil switches.

FIG. 4 WESTINGHOUSE 3300 VOLT, MINING SWITCH PILLAR

The switch portion is removed and standing on the left. The guard which is normally in front of the fixed plugging contacts is shown at the right.

CUBICLES

The majority of Continental installations are built with the apparatus located in cubicles even up to the highest voltages. Great diversity is shown in the choice of structural materials. Ferroconcrete moulded *in situ*, is commonly used. In some countries, notably Italy and Russia, very skillful plasterers are available, and in these countries there are some beautifully light and graceful plastered structures. An Italian workman will make a wall 1.5 or 2 cm thick by plastering on both sides of a sheet of expanded metal. In Scandinavia and Germany effective use is made of sheet insulating material, called "Scagliol" and "Duroplatten". These are of the asbestos lumber family, and are easily cut to shape, so as to make up any desired cubicle structure, using a very light rolled steel supporting frame.

Very commonly the cells containing oil switches or other oil filled apparatus are made with a sill across

fects due to rupturing any power within their breaking capacity rating.

Curiously enough, in places where the oil switch cell design is elaborated in the way described above, it by no means follows that cell doors are used, and thus the additional safety factor in case of fire, which the drain would give, is entirely thrown away. Cell doors or screens are in fact rarely used. Occasionally some slight barrier may be employed, more to attract attention to a danger zone than as a protection from contact. More usually the cell work is left entirely open and the room in which the apparatus is located is kept locked. Typical Continental cubicles are shown in Figs. 8 and 9. Phase barriers are generally omitted from switchgear up to 15 000 or 20 000 volts, if the generating plant is less than ten or fifteen thousand k.v.a. capacity, and also on small substations within these voltage limits. This is recognized by the rules

of the V.D.E. which, although primarily the German standards, are widely accepted and worked to in other continental countries.

On big systems Continental makers will generally employ phase barriers and horizontal shelves between items of apparatus, up to the highest voltages. As will be explained later Messrs, Brown Boveri and the Allmanna Svenska depart from this practice under certain conditions.

In Great Britain it is customary to employ insulators at all points where the conductors pass through a wall or cell barrier. In this way every cell forms a more or less fireproof compartment, and the method of construction may consequently be considered as justified.

On the higher voltages such "through" insulators are expensive, and when pressures of 40 000 volts and over are reached the construction of insulating bushings becomes also a difficult matter from a technical point of view. Continental Engineers in consequence dispense with "through" insulators as far as possible, running the leads through holes left in the cell work. It will be appreciated that such cubicle structures are only fireproof in that they are uninflammable. If a fire were to start in any part of the switchgear there would be very little to hinder it spreading through the whole equipment, even if cell doors were fitted. The sole advantage of a concrete structure such as this is that it enables a man to work on a dead circuit without any risk of accidentally fouling the live connections on adjacent circuits.

FIG. 5—FRONT VIEW OF REYROLLE SWITCHBOARD EQUIPMENT FOR 20 000 VOLTS

The cost of a cubicle structure varies very little with voltages from 25 000 downwards. Above this pressure the cost goes up in almost direct proportion to the voltage. For this reason, and also because, with increased spacings, the probability of making accidental shorts and grounds while working on the apparatus is much reduced, it is common practice among continental builders to modify their cubicle structures on extra high voltages. A typical instance is one of the latest large installations made by the Oerlikon Co.—the Volturno Station in Naples. This is laid out with what may be termed a semi-enclosed concrete structure. Between the poles of the oil switches and other separate pieces of apparatus, there are concrete walls, but these are not built continuously and all interconnections are left entirely without concrete work or barriers of any sort.

On installations of 50 000 volts and over, Brown-Boveri and the Allmanna Svenska have taken the bold course, and in numerous cases dispense entirely with cubicle structure. All apparatus is supported on rolled steel framework. In Fig. 10 is shown an Allmanna Svenska Installation built on these lines.

For several years American manufacturers have consistently avoided the use of cubicles for pressures in excess of 15 000 volts. In the very early days of high voltage work, a few cellular equipments were built, even up to 60 000 volts. The greatly enhanced costs already referred to, coupled with the consideration that with high voltages the destructive effect of an arc is much less than with an equal power at low pressure, have effectually and finally decided them in favor of an open construction. There are no restrictive laws in the United States or Canada which would compel the use of elaborate guarding screens or interlocking devices. Such accessories are in consequence of the simplest character. The layout is always made diagrammatic and the framework so designed as to obscure the apparatus and connections as little as possible, so that it is easy to see the condition of any given circuit.

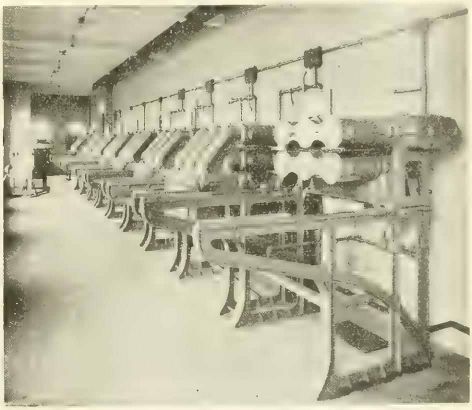

FIG. 6—REAR VIEW OF BOARD SHOWN IN FIG. 5

A happy illustration of these points is given by the layout of the 72 000 volt gear at Point du Bois, City of Winnipeg system, Fig. 11. In this case a tie switch is furnished to link between a duplicate transformer bank and a duplicate transmission line. Such switches are extremely awkward to arrange with cubicle work, but the Winnipeg arrangement is remarkable for its clean-cut appearance and the sufficiency of space around all switches.

OIL SWITCHES

High-voltage Continental oil switches are in general characterised by the large volume of oil they require,

their slow operating speeds and frequently the relatively weak mechanical construction adopted. Doubtless this latter has its origin in the fact that in Europe a large number of small capacity plants are located so far from the point of consumption as to require a very high transmission voltage, although the rupturing capacity of the switch need only be small. The general principle of design on these smaller capacity switches is to mount all three poles on a single carrying frame and to use a common oil tank for all three phases until the weight of the latter becomes too large for convenient handling.

According to the V.D.E. rules any switch for use on 24 000 volts and above must have separate tanks. This does not necessarily mean that entirely separate poles must be employed. The change to this form is more usually made between 30 000 to 35 000 volts.

A few Continental makers, especially on their high breaking capacity switches, are following the practice of lining the tanks which is almost universal in America

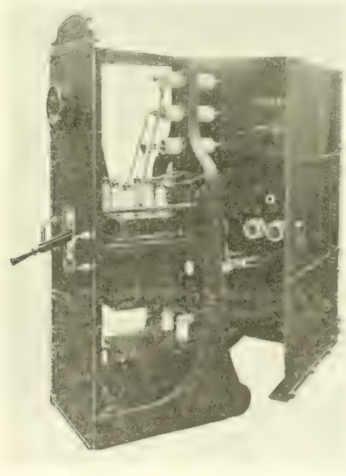

FIG. 7—WESTINGHOUSE TRUCK TYPE PANEL
With truck drawn out to show the guard over the bus-bar plug contacts on the fixed portion.

and in Great Britain. In most cases tank lining is not used and consequently the distance between live metal under oil and the side of the tank is kept great, so as to prevent the arc of rupture going to ground in the tank

Many German and other Continental oil switches have hand-wheel operation, this moving the contact arms through a crankshaft and crosshead system. Such a mechanical system is essentially slower in opening than is an arrangement of toggles. To get the necessary length of break for a high voltage switch within a reasonable time, a common device is to connect in series all the poles of a three-pole switch, and couple three such units together. A three-pole switch with six breaks per pole is thus obtained. Such an arrangement is open to numerous objections. Using the frame of a three pole switch intended for a lower voltage there is always a tendency for the arc to go from fixed contact to fixed contact, and even with this cramped spacing the overall dimensions of a three-pole unit are extremely large. For these reasons the latest, large capacity, high-voltage Continental switches embody a new form of internal mechanism so that a long break can be obtained

FIG. 8—TYPICAL ITALIAN CUBICLE WORK BY MAGRINI

within a single pole unit, the rotary motion usually being transmitted through bevel wheels.

The oil switches built by the Allmanna Svenska stand out among Continental apparatus in that they are primarily intended for lever operation, and the closing and tripping mechanism is a toggle system, much as is commonly used in America and in Great Britain.

Practically all Continental oil switches are fitted with either a wire rope gear or a screw driven platform for lowering the oil tank. The removable tank lowering and transporting carriage is (with the exception of Allmanna Svenska) peculiar to British and American practice. Very large continental switches are usually

FIG. 9—CUBICLE INSTALLATION BY MAGRINI

mounted on rollers so that the whole unit can be removed with ease, once the connections and the mechanical couplings are unfastened.

THROUGH INSULATORS AND BUSHINGS

The design of insulators for use on very high voltages is one of the most fascinating studies in connec-

tion with switchgear work. There is little or no uniformity of practice, different firms having produced bulk type insulators, compound insulators and condenser bushings, all of which can be made to operate satisfactorily although each type suffers from its peculiar disadvantages.

Up to 50 000 to 60 000 volts, solid porcelain insulators may be economically manufactured. Above this figure the porcelain would have to be so thick that it would be hard to ensure the necessary homogeneity, and "through" insulators or bushings must, therefore, be of some other material or type of construction. To a certain extent Bakelite micarta, or Haefelite (a Swiss synthetic insulator of very similar character) has been used for bulk type bushings even up to 120 000 volts. The most usual form of compound insulating bushing used on the Continent consists of a porcelain shell, the space between the shell and the conductor being filled with bitumen, paraffin wax or some such insulating medium. The design of compound insulators calls for considerable care in the selection of dielectrics. The

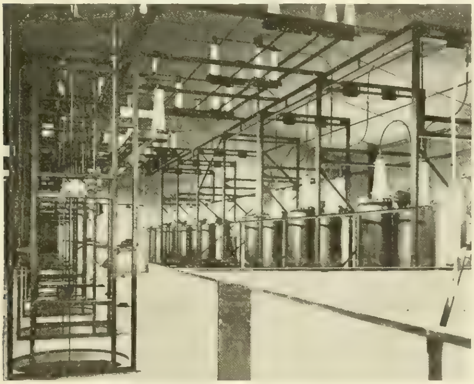

FIG. 10—70 000 VOLT OPEN SWITCHGEAR
Porjus Scheme, Allmanna Svenska.

specific capacities must be such that the potential gradient over the whole insulator is so distributed as not to overstress any one of the component dielectrics, while taking full advantage of the insulating value of each component.

Most bitumen filled bushings have been quite successful, the main difficulties being those of manufacture. It is essential to exclude all air when filling the insulators, and also to provide for expansion of the filling, as the bitumen has a much higher co-efficient of expansion than porcelain. The proper proportions of a bitumen filled bushing renders the diameter at the central mounting ring very large. Apart from this, the outer shells vary considerably in design, ranging from the Ganz insulator which is deeply corrugated over the whole length, to the Brown Boveri insulator which has a perfectly smooth outer surface.

SUPPORTING INSULATORS

The designs of supporting insulators are not subject to such great variation as are bushings, since in this case puncturing voltage does not have to be considered, but only flash-over. Porcelain is used almost exclusively. In most cases the insulators are of the conical post type made in as few pieces as possible. One piece insulators have been made for pressures as high as 70 000 volts. The principal differences are matters of shape, the deeply corrugated insulator still having its adherents, although in most cases any irregularity in the insulator surface partakes more of the character of ornamentation, rather than being an attempt to improve the insulator electrically.

LIGHTNING PROTECTION

Practically all the high voltage systems of the world employ long overhead transmission lines. The protection of these and of the connected apparatus is therefore a matter of first importance.

In the first case it may be well to emphasize the great improvements which have been made in the insulation of connected apparatus. Transformer end

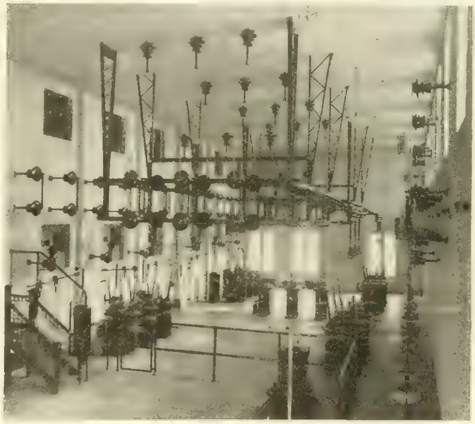

FIG. 11 72 000 VOLT SWITCH ROOM, WINNIPEG CITY

turns are often so well insulated that more than one maker both here and abroad is prepared to connect them direct to a line without any intervening choke coils before the lightning arrester equipment.

In Sweden there are a few installations (at 20 000, 40 000 and even 70 000 volts) in which no over-voltage protection other than drainage coils is employed. It must be borne in mind that the lightning storms encountered in Sweden are by no means as severe as would be the case in Central and Southern Europe, or in America. It is interesting in this connection to note that the first 100 000 volt installation in America, namely that of the Grand Rapids Muskegon Power Company, had their transformers connected direct to the line without any switching devices, choke coils or arresters. In this manner they worked satisfactorily for many years. Later additions to the same system using 140 000 volts have had switchgear and arresters in the high-tension circuits.

Practically all Continental lightning arrester designs (and their name is legion) hinge around the use of the horn gap originally used by Siemens, operating in conjunction with a water jet. Usually the horn gap (or two or more horn gaps in series on high voltages) is arranged with a resistance in series to ground, the sets of horns and resistances being in star. The horn gaps are set with such a gap that the "spill-over" voltage is about 150 to 180 percent of normal line voltage, and the resistance serves to limit to a safe value the flow of dynamic current following on a discharge.

The general value of resistance is such that the dynamic current is limited to between one and ten amperes; five amperes may be taken as a very usual figure. If the resistance be too high the freedom of discharge will be affected. The resistance itself is either of the oil-immersed wire wound type or consists of a column of water within an earthenware pipe.

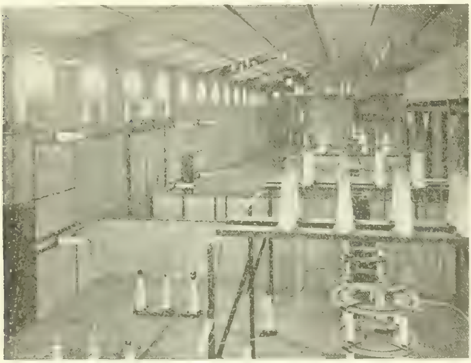

FIG. 12 80,000 VOLT LIGHTNING ARRESTERS
Porjus Scheme, Allmanna Svenska.

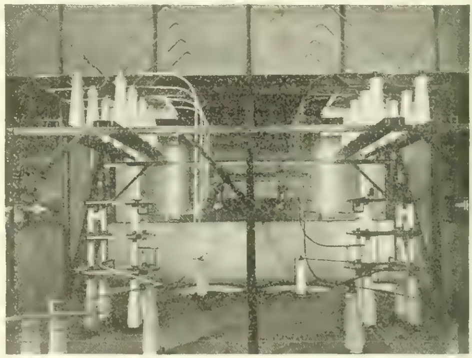

FIG. 13 DETAILS OF LIGHTNING ARRESTER INSTALLATION SHOWN IN FIG. 12

Some engineers adopt the alternative of using horns set to about double line voltage and connected direct to ground without any resistance whatsoever. This arrangement will best relieve the system of all over pressures exceeding that for which the horns are set. If two or more horns operate simultaneously, however, the result is a phase-to-phase short-circuit; or should a single horn spill over, the effect is that of an arcing ground, of varying resistance as the arc rises up the horns.

As stated above it is usual to employ a water-jet device as well as the horns, the former serving to relieve minor over pressures. The water-jet is usually installed close to the end of each overhead line, but where expense is of first importance, or where the length of the line is short, it is sometimes connected direct to the bus-bar system. As the name implies, the apparatus consists in a solid stream of water which is kept constantly playing on each of the three lines. An ammeter is usually connected in series and the length and section of the jet are such that under normal line voltage a current of from 0.1 to 0.2 amperes constantly flows to ground. This means an annual power loss of at least 1500 kw-hrs. per kilovolt line pressure. This apparatus really functions at voltages between normal line pressures and the critical setting of the horn arresters. It cannot be employed by itself as the water column would present too high a resistance to relieve properly the effects of lightning. American experience shows conclusively that the minor over pressures are in no way to be feared, and that the protection afforded by water-jet devices is not worth the initial outlay and the annual cost of wasted power.

In addition to the apparatus mentioned above, there are numerous devices which are less widely applied. Among these may be cited low equivalent (Wurts) arresters, the Siemens multiple choker and horn apparatus, shown in Figs. 12 and 13; the Gola horn and condenser arrester; the Pizzuti and Ferrari combination of horns, chokers and condensers; and the Mosckiki and Fribourg condensers. It would seem to be without the scope of this paper to deal with these in any detail, as they cannot be considered as truly representative.

The Engineer and the Community

E. H. Sniffin

IT IS USEFUL sometimes to stand off a little way and take a view of your work, the field of your activity and its relation to the general scheme of things. To go up on a mountain, so to speak, and look down upon the world, to ponder what its inhabitants are all doing and why, and where you fit into the plan. One may well muse over the purpose of it all. It seems like a very fair earth, where men ought to be very decent and very comfortable. Then why have they made such a sorry mess of it? Perhaps it is in the divine scheme that they should make a mess of it. We know there has always been a terrible struggle, perhaps always will be, for the things that bring us food, covering, shelter and delight for the senses, and the landscape will soften very gradually as men slowly learn that it is not a struggle of units, but a struggle of humanity in the mass; that we cannot live alone, but that we depend upon each other and that the one substantial happiness that comes to any man is to be measured by the extent of his service to others.

And so I cannot talk about the engineer until I find his place in this scheme of things; and when I see what he has done for the world, when I find that within the last century he has practically revolutionized the living conditions of civilized people and made the world more habitable than was even dreamed of by the greatest imaginations of former ages, I am bound to conclude that the engineer, perhaps above all others, has contributed most to the material welfare of humanity. What is known as the world's industrial revolution began about a hundred years ago when by the application of steam as motive power and the inventions of machines for various purposes which it stimulated, and the onward march of scientific discovery, there followed the age which has culminated in our own day in a world transformation. And what a romance it has been, this work of the engineer. Not alone for money gain has he labored, albeit he has made it for others, but to him has come a wealth greater—

> "Than all Bocara's vaunted gold,
> Than all the gems of Samarcand."

the consciousness of a great world service. He has hitched his wagon to a star. Do you remember that beautiful poem of Kipling's which begins—

> "When earth's last picture is painted,
> And the tubes are twisted and dried."

and then he describes that heavenly existence where—

> "No one shall work for money,
> And no one shall work for fame,
> But each for the joy of the working,
> And each in his separate star,
> Shall draw the thing as he sees it,
> For the God of things as they are."

The engineer does not have to die to do that. He does it while he is here. He has been the interpreter of physical facts and natural laws and marshalled them into useful paths of world employment. He has "drawn the thing as he sees it, for the God of things as they are". I sometimes imagine when I look at a great piece of engineering work,—an ocean steamer, a long span of bridge, a big dam, an immense power-house,—that if the creator of it should have passed into the shadows, his soul must still hover near this monument of its earthly expression, for that would be Heaven indeed.

And it is this feeling that I have for the engineer, the love and esteem I hold for him, that prompts me to discuss "The Engineer and the Community". Or to put my meaning in the form of a question,—why is not the engineer a more conspicuous member of the community? The query is by no means original with me. It is beginning to concern the engineer himself. It has been accentuated perhaps by his large contribution to our victory in the great war, not only through his engineering achievements, but his power of organization and administration, the employment of a mind trained to deal with facts and form accurate conclusions. It has been the frequent topic before many of our engineering societies. Only thirty days ago there was held at New York an engineers' symposium on the topic of "The Engineer as a Citizen". Many engineering societies were represented. The trend of discussion bore particularly upon the question of what the various societies might do to extend their useful influence toward proper legislation on questions coming within the sphere of their specialized knowledge. Mr. Townley told of several occasions when the A. I. E. E. had been invited by the Government to send committees to discuss engineering questions involved in certain bills and measures under consideration. On these occasions the committees were instructed to confine their interests strictly to statements of engineering and allied facts not embraced within the field of controversy, but to avoid expression as to the wording of any bills or to give opinions on legal matters. On two occasions joint committees representing the National engineering societies have appeared before legislative bodies in opposition to bills which they considered inimical to the engineer in particular and the public in general. The joint committee of the various societies was continued for some years and finally resulted in the organization of the Engineering Council. This Council has existed since May 1917. It is authorized to speak for its constituent societies on matters of common concern to engineers and to afford a means for joint action when desirable. The Council has examined and reported upon a great deal of pending legislation and has passed numerous resolutions to the societies favoring or opposing proposed laws. With the close of the war came a very in-

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*From an address before the Baltimore Section, A.I.E.E., April 25, 1919.

sistent demand that the engineers of the country be represented at Washington during the reconstruction period, and there was appointed a National Service Committee, having an office in Washington, comprised of a chairman and two prominent representatives from each of the four founder societies. Engineers in general have apparently welcomed this means of acquiring first hand information from those they deem qualified to give it at the scene of action. All this will show you that our societies have been evincing a good deal of interest in public matters, embracing questions that come within their professional experience and knowledge, but it may be said that up to the present time they have remained aloof from general public or political activities.

My own opinion is that our various engineering societies, as such, should not in their public aspect let down the barriers which now distinguish them in the world's respect. I believe it to be not a question of the good they might do if their influence were exerted upon matters of public weal coming before legislative bodies or directly before the electorate, but rather the danger there is of a suspicion that would impair the present authority which they hold in the public mind. It sometimes takes the public a long time to recognize the truth, and often very little will divert it from the true path. The great discoverers of truth have usually been canonized long after they have died of broken bodies or broken hearts. But the people do want the truth and if there be a sanctuary where they know it presides let it be maintained inviolate.

I think there is no doubt that our scientific bodies have gained as much headway in the public esteem as we could well expect considering the conditions of our National growth and the meager time we have had for reflection. They will continue to exert greater authority under the refining influence of the scientific methods that must inevitably follow our cruder methods of the past.

The problem, it seems to me, lies more particularly with the engineer as an individual and that is the chief thought in my mind. Why is he not a more conspicuous citizen? Why do we not have more of the benefit of his trained mind in our public affairs? Is he to be so highly specialized in his profession as not to be a man among men, he of the trained mind, and not help to solve the problems common to us all? Shall we leave it to the lawyers to hold public offices? If so, I am wondering what special qualifications the lawyer has for the public service that the engineer does not possess, or at least might not readily acquire. I can very easily imagine that the engineer in his lifetime search for facts, for the truth of things, dealing as he must with economic problems which suffer no gloss or guile, might indeed be a very valuable public servant. I am told that the membership of the Sixty-Fifth Congress contains not a single engineer in either the Upper or Lower House. It must be a matter of chagrin to us, when we come to think of it, that in our country with its wonderful scientific and mechanical achievements which have been the biggest thing in our development, there stand out very few men among our engineers or scientists whose voice is heard in our National councils. What a pity; and how much better it would be for the country if the reverse were true.

I think the trouble starts at the school. I am glad to say that that feature is improving, but I think rather slowly. As a rule technical school graduates have shown too much the effect of a specialized training at the expense of an education. The engineer seems to be stamped upon them at the expense of the man. Their general interest in things has not been stimulated. They have not the catholicity of taste or ready response to environment that marks the well rounded man. Then followed their years of work, their concentration upon the thing they loved, with little heed for the verities or amenities of our common social existence. I do not complain of the engineer's usefulness. There is nothing but praise to be said for the value of his work. But he lives in a world of men who have their own way of appraising his value and I am contending that he has the training that will enable him to serve them in a greater degree still, if he will come out of his hermitage and mingle with the open world. We must remember that in our own country there is very little spontaneity of recognition of the men of science. In the older countries they are selected for distinguished honors. Great Britain knights her Thompsons, her Parsons, her Whitworths, her Bessemers, a long list of them who take place with her statesmen, her scholars, her publicists. Poincare, the President of France, is said to be one of the world's great mathematicians. Clemenceau was once a physician, and I am told there are about seventy physicians in the present Chamber of Deputies. And Paderewski is now running Poland. If this artist, who I suppose is temperamental, can leave his keyboard and work with all his brain and brawn and heart and soul for the nationality of his country, what do you suppose the engineer might do? Artist that he is, he fits very well into my theme. Our first President was an engineer. Franklin was a scientist. But both of these great men had other compelling interests that made their names immortal. The habit went out of fashion at an early date.

The fact is that our own country is not inclined to exalt a man into realms of distinction beyond his definite accomplishment, although it does quickly recognize him for what he does, and it is as true of human nature here as elsewhere, that your light gives better illumination when exposed than when hid under a bushel. Our friend, the engineer, is too modest. Any man would be who spends his life struggling with natural laws; he finds out how small he is. And I suppose it to be natural that he should view with but casual interest the many phases of our social life, and especially the banalities, as he sees it, of politics. So he keeps aloof from all these trifling, artificial, unsubstantial affairs, and remains the engineer. And the public

lets him have his way. Now this is undoubtedly very wrong. There is nothing more true than the fact that people live upon the earth in a social state of interdependence, the most successful of them under representative forms of Government. Through these representatives National, state and municipal laws and local ordinances are enacted, supposed to give the maximum benefit to the greatest number. These important functions are exercised often from political motives purely. Very often the motive is honest and sincere, but the result is unwise, unsound and sometimes vicious in its consequences. Do you suppose, for instance, that the hydroelectric situation in our country to-day would have existed had there been among our law makers enough men with the engineering and economic knowledge to know what they were doing? No, it required a world war, with its stress upon every ounce of our National energy to make us fully realize that we have about twice as much undeveloped water power in this country as there is steam power in use, including locomotives, scarcely any of which will invite a dollar of capital under our present ill-considered laws. So the President is now trying to speed up the remedial legislation that has been under consideration for many years.

But, as I said before, the engineer will not be picked from his profession to serve in public life. He must himself show social and public activity. He must make men aware of him. I wonder if I might say he must advertise himself—that word "advertise" has a new significance to me since I have seen how necessary and successful it was in such a good and worthy cause as our Liberty bond campaigns. When Emerson said that if you could do something better than any one else could do it, the world would make a path to your door, even though you lived in the heart of a wood, he had in mind only one phase of human nature. It is equally a fact that the greatest truth that was ever established will be accepted more readily if it hits you in the face at every turn. Not as an engineer shall he advertise, but as a man of superior mind, who in the sweep of his knowledge and the sincerity of his purpose shall become a strong and helpful influence in our public affairs. We are living in a critical period of the world's history. We have just expended nearly ten million lives and two hundred billions of wealth, and were ready to give all our lives and all our wealth to preserve our heritage of freedom and righteousness. Thrones have been demolished and Governments upset and the world is trying to find its way, let us hope, to a new and better order of existence. Meanwhile there are tens of millions of people living under conditions of social chaos, and it would be a bold man who could say how far it will go, or indeed, whether our own fair land shall be immune from the blight of these poisonous theories that have already spread from the Volga to the Rhine. Let us hope not. But let us make sure that it shall be every man's duty to come out of his isolation into his fullest obligations of citizenship; that men of trained mind and trained character shall seek their places in the councils of our country; and that the engineer above all others shall no longer exclude himself from the fullest measure of public service.

The Design of Large Induction Motors

For Steel Mill Work

H. L. Barnholdt
Industrial Engineering Dept.,
Westinghouse Electric & Mfg. Company

THE "Do it electrically" slogan can find no better advertisement than the success which has attended, from the first, the introduction of electric power for driving the main rolls in steel mills. This success has been due mainly to the inherent reliability of the type of motor chosen by the mill engineers for this application and to the fact that electrification at once provided an easy and accurate way of determining the power consumption of the violently fluctuating loads encountered in the rolling of steel, thus enabling the manufacturer to analyze and definitely fix the requirements to be met in the motor design. These requirements, such as ability to carry heavy peaks of overload safely, insulation to withstand the adverse atmospheric condition prevalent in steel mills, accessibility for inspection and overhauling and for making quick repairs in case of accident, can all be summed up in the words *continuity of service* which is the paramount requirement of this application. The proverbial "prince or pauper" condition of the steel industry makes this point all the more important, for in times of trade expansion it is often imperative that the mills should be

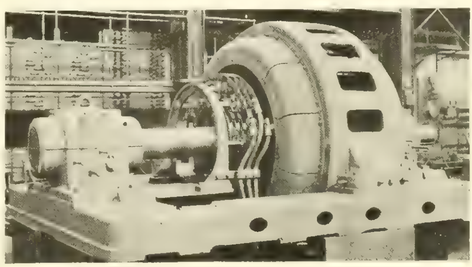


FIG. 1—1500 HP, 505 R.P.M. ROLLING MILL MOTOR SHOWING TYPE OF CONSTRUCTION USED FOR UNITS OF MEDIUM SIZE

capable of rolling steel without interruption over long periods of time.

The first installations of electric motors for driving of roll trains in steel mills were made in 1905 and the design of the first motors was quite special, sometimes reflecting widely differing individual ideas of the requirements. This was natural, for pioneering and standardization do not go hand in hand. Gradually, through years of experience a distinct type of motor was developed for this service by eliminating undesirable and unnecessary features while retaining or adding desirable ones.

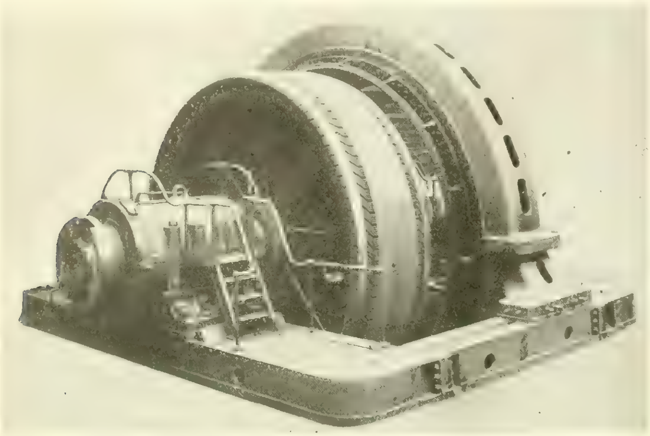


FIG 2 6000 HP, 86 R.P.M. MOTOR FOR DRIVING THE RAIL MILL AT THE DULUTH PLANT OF THE MINNESOTA STEEL COMPANY

This type of construction is used for the larger units. The stator is slid aside for access to stator and rotor windings.

As a rule there are no restrictions in regard to space or weight of motors for this application. In the electrical design, therefore, the proportions can be determined entirely with the view of producing a machine that will fulfill most economically all of the service requirements, considering first cost together with upkeep charges and performance. Questions relating to operation are naturally given preference over those of performance. For instance, it is better policy to use a relatively small number of slots with coils of substantial cross-section instead of endeavoring to gain one or two percent in power-factor by using a larger number of slots, necessitating small and more or less flimsy coils with consequent increased risk of breakdown.

A typical motor for this application is shown in Fig. 1. Usually, the mills are equipped with heavy flywheels and, to provide for easy starting conditions, the wound rotor construction is adopted which permits the use of external resistance in the rotor circuits so that the energy stored in the flywheel may be utilized to assist the motor in carrying peak loads. By using pedestal type bearings, ready provisions can be made for sliding the stator to one side, making it an easy operation to expose the rotor completely without disturbing the alignment of the shaft, Fig. 2.

STATOR

The necessary strength and rigidity required of the stator are obtained by using a box-type cast-iron frame of liberal proportions with the supporting feet located near the horizontal center plane and cast integral with the frame. The feet have screws and liners for horizontal and vertical adjustment so that the stator can be moved by fine increments in any direction for purpose of lining up the air-gap and to take up for any wear of bearings. The laminations are dovetailed into ribs in the frame casting and are clamped between heavy end plates with fingers for supporting the teeth. The slots are of the straight open type and the winding is composed of duplicate coils completely formed and insulated before being placed in the slots.

In order to withstand severe service under the adverse atmospheric conditions existing in steel mills, it is necessary that the insulation of the windings should be of the very best obtainable. This applies particularly to that part of the winding which is imbedded in the core and the solution of the problem here lies in the use of mica. Mica possesses an admirable combination of great dielectric strength and high heat resistive qualities, in fact its insulation resistance increases with temperature. It is also resilient and retains its resiliency indefinitely, thus helping to hold the coils tightly in the slots. For the purpose of applying it on the coils, the mica laminations and fish paper are bound together into sheets by means of a special compound. These sheets are wrapped around the straight part of the coil and are then held on by means of cotton tape which serves as a mechanical binder. The coil ends projecting outside of the core where the demands on insulation are not as great and where more flexibility is required are insulated with treated cloth. To guard against the metallic dust so prevalent in steel mill atmosphere, it is essential that all joints in the insulation be effectively sealed. The windings must be well braced so as to withstand mechanical vibrations and surges due to

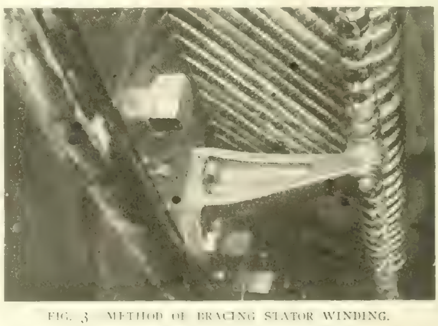


FIG. 3 METHOD OF BRACING STATOR WINDING.

switching and extreme fluctuations in load. The slot portion of the coil is held by wedges driven into grooves in the sides of the teeth and the coil ends are braced by lacing each coil to an insulated steel ring supported from the stator frame. The windings are protected

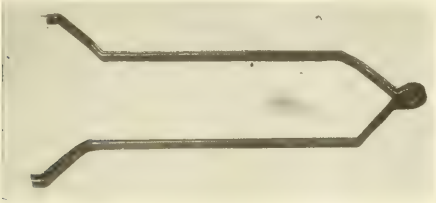


FIG. 4—TYPICAL ROTOR COIL, FORMED TO EXACT SHAPE AND COMPLETELY INSULATED BEFORE ASSEMBLY

against injuries from external sources by means of suitable cast iron end-bells bolted to the stator frame.

ROTOR

The rotor has to take the brunt of the shocks and vibrations transmitted from the mill. Also it must be capable of being reversed from full speed and at full line voltage, when required to make a quick stop and withstand the severe insulation and mechanical strains imposed by that operation. To this end the rotor is built up on a strong, rugged double arm spider usually made from cast steel, with the laminations dovetailed into the spider and clamped between heavy end plates with fingers for supporting the teeth. These end-plates also form a support for the projecting coil ends. A special feature found in Westinghouse rotor slot and coil construction, is the use of form-wound coils similar to those used in straight open-slot construction, without sacrificing the superior performance characteristics inherent in the partially-closed type of slot. Fig. 4 shows a typical rotor coil consisting of two copper straps side by side, each strap being formed to exact

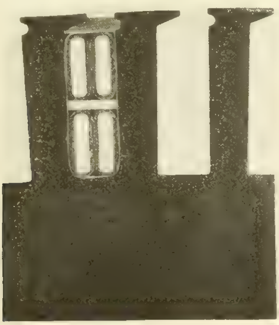


FIG. 5—SECTION THROUGH ROTOR COILS AND SLOTS
The opening at top of slot is of sufficient size to allow dropping in one fully insulated coil section at a time.

shape and completely insulated before assembly. Fig. 5 shows a section through coils and slot, there being usually two coils per slot. The opening at the top of the slot is sufficient to allow one fully insulated strap to be dropped in at a time, so that inspection and testing can be easily made effective on each individual coil and there is no forming or insulation operation performed after the coils are put into the slots. The only drawback to such a construction is the relatively high cost of the formers required. However, this method gives excellent insurance of a good job being done at the factory and so facilitates the removal of coils for repair, in case of accident, that its slightly higher cost as compared with other constructions is more than justified.

One may ask why this type of construction is not used also on the stator. The answer is that while it is thoroughly practicable even on the largest machines to design rotor windings having only four straps per slot, it is necessary to subdivide the stator coils into a greater number of strands depending on the line voltage and in order to minimize the effect of eddy currents which effect would often be serious if heavy straps were

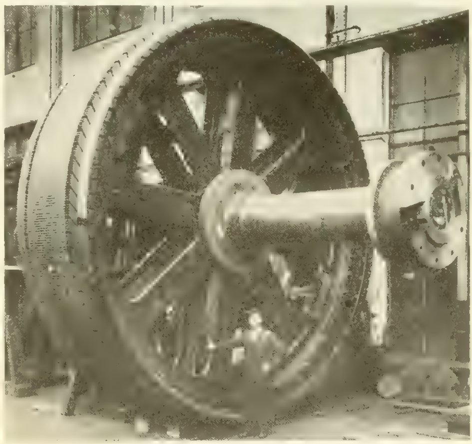


FIG. 6 ROTOR FOR 6000 HP, 86 R.P.M. MOTOR

used for stator coils, but is insignificant in the case of rotor coils due to the low secondary frequency. For coils composed of a relatively large number of strands the straight open-type slot is the best construction for this application. The rotor insulation itself is of the same general character as described for the stator. The slots are lined with a fish paper cell which is not depended upon as insulation but simply serves to protect the coil from injury by the iron core during the process of assembly. After all the coils have been assembled and the top wedges driven in, the winding is connected and the banding applied, a view of a finished rotor being shown in Fig. 6.

VENTILATION

These machines often have relatively wide cores and their proper ventilation is one of the important problems that confront the designer. The cores are provided with radial air ducts placed at frequent intervals through which the cooling air is forced by the centrifugal action of the rotor. These air ducts have

to be made liberal in size so as not to become clogged with mill dust and to facilitate blowing out when cleaning the motor. In addition, the rotor carries a fan on each side and the end bells bolted to the sides of the frame are shaped to guide the air supplied by these fans

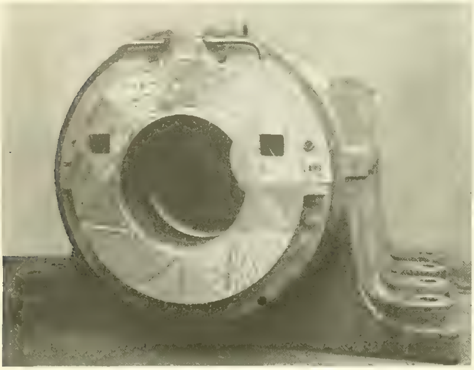
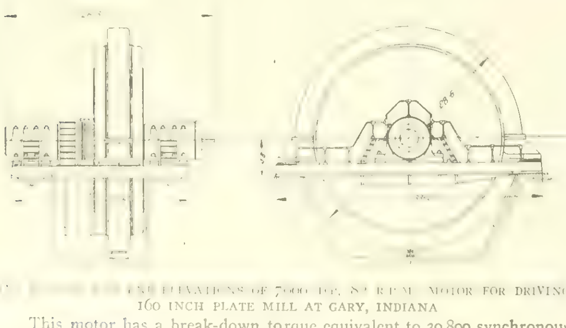


FIG. 7—LARGE PEDESTAL BEARING EQUIPPED WITH END THRUST BEARING

around the coil ends to the back of the stator core where exhaust openings are provided in the frame. The entire system of ventilation is designed so as to bring the cooling air in direct contact with all parts of the machine where the heat is generated, thereby preventing "hot spots."

PEDESTAL BEARINGS AND SHAFT

The shocks and vibrations from the mill are transmitted to the pedestal bearings which must be made very strong and rigid. This is accomplished by using low bearing centers and by rugged pedestal design. It is generally practicable to make the pedestals rugged enough by the use of cast iron, but cast steel may be necessary in extreme cases where heavy end thrusts have to be taken up. The bearings are babbitt lined



[illegible] ELEVATIONS OF 7000 HP, [illegible] R.P.M. MOTOR FOR DRIVING 160 INCH PLATE MILL AT GARY, INDIANA

This motor has a break-down torque equivalent to 30 800 synchronous hp and is the largest power induction motor in the world.

and are designed to operate continuously with oil ring lubrication only. They are also piped for forced oil feed as an emergency feature. The bearings are split through the horizontal diameter and are so designed that the top half can be readily removed for examination of the journal and the bottom half rolled out without more than relieving the bearing of the shaft weight. The bearings are made dust proof by means of felt packing at the oil hole covers and around the shaft.

Where an end thrust bearing is required, the stationary half is mounted on the end of the pedestal housing. This half is faced with babbitt and is provided with shims or liners for adjusting the end play. The revolving half of the thrust bearing is made up of the coupling hub, enlarged at the end which is finished to a true bearing surface after the coupling is pressed on the shaft. A wool waste oil feed is used mostly and the

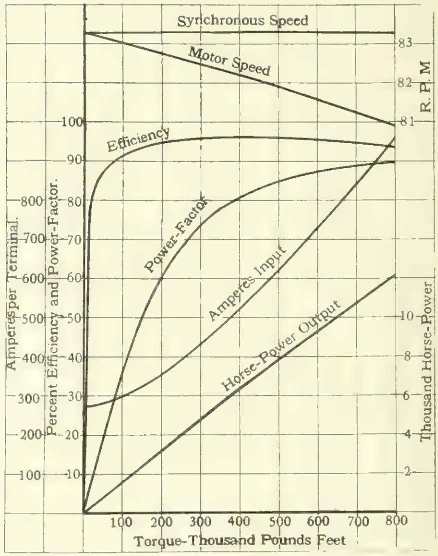


FIG. 9—PERFORMANCE CURVES OF 7000 HP MOTOR

entire thrust bearing is enclosed in a dust proof casing bolted to the pedestal housing. The shaft is made of forged steel and is provided with suitable oil throwers to prevent oil from creeping out of the bearing housings.

BED PLATE

The bed plate which carries the stator and the pedestals is made of cast iron of heavy box type pattern. The machined surfaces under the frame feet are extended to one side and are provided with barring holes so the stator may be slid parallel to the shaft, thereby giving free access to both stator and rotor winding.

THE LARGEST INDUCTION MOTOR IN THE WORLD

While in general the rolling of steel requires high power machinery, it is of interest to note that the 7000 horse-power induction motor which was put in operation some time ago at the Gary plant of the United States Steel Corporation constitutes a new record in size of unit. The motor is directly connected to a 160 inch, three high plate mill and is rated

7000 horse-power, 3 phase, 25 cycle, 6600 volts, 82 r.p.m. at a temperature rise of 40 degrees C. It also has a continuous rating of 8750 horse-power at 50 degrees C. rise. The maximum running torque was required to be not less than 28 000 synchronous horse-power and tests showed the same to be 30 800 synchronous horse-power, equal to a torque of 1 940 000 lbs. at one foot radius, thus making it by far the highest power induction motor that has ever been built. In the case of this motor it was decided to incorporate in the rotor the total flywheel effect required, $WR^2 = 16\,000\,000$. This was accomplished by making the rotor construction extra strong and heavy and by using circular rim weights made of cast steel, one fitted to each side of the spider. The total net weight of the motor is 598 000 pounds.

From the performance curve Fig. 9, it will be noted that the efficiency is maintained at a very high value, in fact well above 95 percent over a wide range of load. The relatively low power-factor is explained by the unusual breakdown torque required, necessitating high flux values and magnetizing currents. An idea of the power of this motor may be had from the fact that once, when the mill became clogged, a hardened steel roll 44 inches in diameter was broken without the motor showing any sign of distress or even slowing down in speed.

There is no particular reason for expecting that this large motor will continue to stand as a record very long in the future. The enormous volume of steel production during the war emergency was maintained chiefly by machinery already at hand or by such new machinery as could be obtained quickly, as there was no time to make designs or patterns for brand new equipment even if by so doing an economical gain could have been made. However, in times to come many plants will no doubt have to be re-modeled and electrified in order to meet keener world competition in the steel industry. If the solution of this problem should be found in the employment of still larger mill units, the limitation lies not with the driving motor, for with reasonable speeds there is no limit in sight of the capacity of motors that can be built for this application.

Reactance Values for Rectangular Conductors

H. B. Dwight

RECTANGULAR or strap conductors are often used to carry heavy alternating-currents in bus-bars on switchboards, in the supply circuits of electric furnaces and elsewhere. The reactance drop in such circuits is most conveniently determined from a set of curves, since the formulas which would be required for calculating the result are rather long and complicated. Such a set of curves is given in Fig. 1.

Very little explanation is required for using these curves. The curves apply to a single-phase circuit of solid strap conductors but, as shown in the examples which follow, the curves may be used conveniently for three-phase circuits and for ventilated conductors, by making use of the fact that the reactance as plotted is proportional to the difference between the self-inductance and the mutual inductance of two straps. It is assumed that the rectangular conductors in a circuit are of the same size and are placed symmetrically opposite each other, as is nearly always the case in practice. Values of reactance are given both for straps in parallel planes, (a less than b) and for straps lying edgewise to each other (b less than a). The reactance values are plotted in microhms at 60 cycles, and the values at 25 cycles or any other frequency can be obtained by modifying the plotted values in proportion to the frequency.

Example I—Find the voltage drop due to reactance in a single-phase, 60 cycle, 2000 ampere electric furnace circuit made up of two copper straps each 50 feet long, size 0.5 by 4 inches, in parallel planes, the distance between centers of straps being one inch.

$$\frac{a}{b} = \frac{1}{8} \text{ and } \frac{s}{a+b} = \frac{1}{4.5} = 0.22$$

Reactance, from curves = 11.0 microhms per foot of strap.
Reactive drop = $11.0 \times 10^{-6} \times 50 \times 2 \times 2000 = 2.2$ volts.

Example II—Find the reactive drop in a three-phase, 60 cycle, 750 ampere per phase circuit made up of three copper straps each 100 feet long, size 0.25 by 3 inches, in parallel planes, the distance between centers of straps being 1.5 inches.

Let the three straps side by side be called A, B and C.

Let $I_A = 750$ *amperes*

$$I_B = -375 + j\,375\sqrt{3} \text{ amperes}$$

and $I_C = -375 - j\,375\sqrt{3}$ *amperes*

The reactive drop in A per foot is,—

$$2\pi \times 60\,[I_A L_A + I_B M_{AB} + I_C M_{AC}]$$

Where L_A is the self-inductance of A per foot, and M_{AB} is the mutual inductance of A and B per foot, etc.

Since, $I_A = -(I_B + I_C)$ the reactive drop in A per foot

$$= 2\pi \times 60\,[I_B(M_{AB} - L_A) + I_C(M_{AC} - L_A)]$$
$$= -I_B X_{AB} - I_C X_{AC}$$

Where X_{AB} is the reactance per foot of conductor of the single-phase circuit composed of A and B. This can be obtained from the curves of Fig. 1.

Thus, $X_{AB} = 21.5$ microhms per foot of strap, since

$$\frac{a}{b} = \frac{1}{12} \text{ and } \frac{s}{a+b} = \frac{1.5}{3.25} = 0.462$$

also, $X_{AC} = 34.0$ microhms per foot of strap, since

$$\frac{a}{b} = \frac{1}{12} \text{ and } \frac{s}{a+b} = \frac{3}{3.25} = 0.924$$

The total reactive drop in conductor A

$$= (375 - j\,375\sqrt{3})\,21.5 \times 10^{-6} \times 100 +$$
$$(375 + j\,375\sqrt{3})\,34.0 \times 10^{-6} \times 100 \text{ volts}$$
$$= 2.08 + j\,0.81 \text{ volts} = 2.23 \text{ volts, numerical value.}$$

The reactive drop in B

$$= -I_C X_{BC} - I_A X_{AB}$$
$$(375 + j\,375\sqrt{3})\,21.5 \times 10^{-6} \times 100$$
$$- 750 \times 21.5 \times 10^{-6} \times 100 \text{ volts}$$
$$= -0.81 + j\,1.40 \text{ volts} = 1.62 \text{ volts, numerical value}$$

The reactive drop in conductor C has the same numerical value, 2.23 volts, as the reactive drop in A.

A circuit of this kind is usually not transposed, and the unbalance in voltage drop will cause an unbalance in current and phase. The average reactive drop in each strap is 2.03 volts, which should be expressed as a percentage of the star voltage.

Example III—Find the reactive drop in a single-phase, 60 cycle, 900 ampere, ventilated bus-bar circuit, each bus-bar consisting of two straps at 0.5 inch centers, size 0.125 by 3 inches and 70 feet long. The distance between centers of bus-bars is 2.5 inches, Fig. 2.

Neglecting circulating currents, each strap will carry 450 amperes. The drop in conductor A per foot is,—

$$2\pi \times 60\ (L_A + M_{AB} - M_{AC} - M_{AD}) \times 450$$
$$= 2\pi \times 60\ (L_A - M_{AC} + L_A - M_{AD} - L_A + M_{AB}) \times 450$$
$$= 450\ (X_{AC} + X_{AD} - X_{AB})$$
$$= 450\ (31.5 + 35.0 - 9.0) \times 10^{-6} \textit{ volts per foot, from Fig. 1}$$

The reactive drop in A is,—

$$450 \times 57.5 \times 10^{-6} \times 70 = 1.81 \textit{ volts.}$$

In a similar way the drop in B is found to be,—

$$450\ (X_{BC} + X_{BD} - X_{AB}) \times 70$$
$$= 450\ (27.5 + 31.5 - 9.0) \times 10^{-6} \times 70 = 1.57 \textit{ volts}$$

The difference in the voltage drop of A and B will be equalized by an unbalance of current, which is equivalent to a circulating current. The average reactive drop in the complete bus-bar is 1.69 volts. The drop in the single-phase circuit comprising both bus-bars is 3.38 volts.

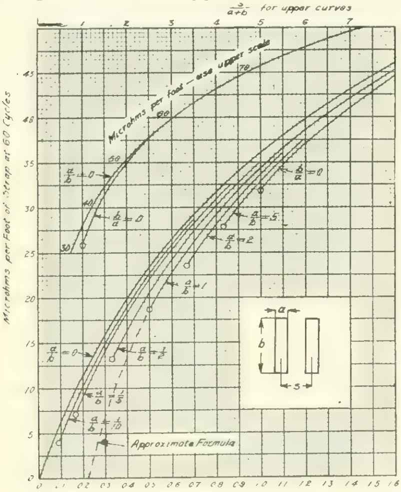


FIG. 1 REACTANCE OF STRAP CONDUCTORS AT 60 CYCLES

For an approximate calculation, each bus-bar may be treated as a solid strap of the same outside dimensions as the ventilated bus-bars, namely, 0.625 by 3 inches.

$$\text{Then, } \frac{a}{b} = [illegible] \text{ and } \frac{s}{a+b} = \frac{2.5}{3.625} = 0.69$$

From Fig. 1, the reactive drop in the single-phase circuit is,—

$$[illegible] \times 70 \times [illegible] = 3.3[illegible] \textit{ volts.}$$

In a manner similar to the above example and example II, the reactive drop in a three-phase ventilated bus-bar circuit can be determined.

The following formulas are given for reference. Approximate formulas for widely-spaced straps,—

$$L = 2\ logh \left(\frac{s}{a+b}\right) + 3 \ldots\ldots\ldots\ldots\ldots\ldots\ (1)^*$$

abhenrys per centimeter of strap, where logh denotes the hyperbolic or natural logarithm. This becomes,—

$$X = 52.9\ log_{10} \left(\frac{s}{a+b}\right) + 34.5 \ldots\ldots\ldots\ (2)†$$

microhms per foot of strap at 60 cycles.

The above formulas give very accurate results for larger spacings than those indicated in Fig. 1, but the results are inaccurate with close spacings. (See the dotted line of Fig. 1).

Formula for thin straps very close together,—

$$L = \frac{\pi}{b}\left(2s - 2a + \frac{4a}{3}\right) = \frac{\pi}{b}\left(2s - \frac{2a}{3}\right) \ldots\ldots\ (3)^{**}$$

abhenrys per centimeter of strap, where a is less than b. This is a straight line formula, and if the corresponding reactance values are plotted on Fig. 1, they are found to lie on straight lines parallel to the curves at their lowest points. For this case the magnitude of the skin effect can be calculated.

Formula for two equal rectangular conductors, placed as in Fig. 1.

$$L = 2\ logh \frac{R_2}{R_1}$$

abhenrys per centimeter of strap, where

$$logh\ R_1 = \frac{1}{2}\ logh\ (a^2 + b^2) - \frac{1}{12}\frac{a^2}{b^2} logh \left(\frac{a^2+b^2}{a^2}\right) - \frac{1}{12}\frac{b^2}{a^2}\ logh \left(\frac{a^2+b^2}{b^2}\right) + \frac{2}{3}\frac{a}{b} tan^{-1}\frac{b}{a} + \frac{2}{3}\frac{b}{a}\ tan^{-1}\frac{a}{b} - \frac{25}{12}.\ (5)††$$

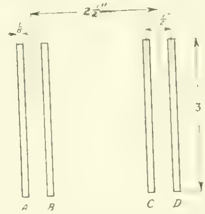


FIG. 2—VENTILATED BUS-BAR CIRCUIT

$$\text{and where } a^2 b^2\ logh\ R_2 = \frac{1}{4}\left[(s+a)^2\left\{b^2 - \frac{(s+a)^2}{6}\right\} - \frac{b^4}{6}\right] logh\left\{(s+a)^2 + b^2\right\} + \frac{1}{4}\left[(s-a)^2\left\{b^2 - \frac{(s-a)^2}{6}\right\} - \frac{b^4}{6}\right] logh\left\{(s-a)^2 + b^2\right\} - \frac{1}{2}\left[s^2\left\{b^2 - \frac{s^2}{6}\right\} - \frac{b^4}{6}\right] logh\left\{s^2 + b^2\right\} + \frac{1}{12}(s+a)^4\ logh\ (s+a) + \frac{1}{12}(s-a)^4\ logh\ (s-a) - \frac{1}{6} s^4\ logh\ s + \frac{1}{3}\left\{b\ (s+a)^3 - b^3\ (s+a)\right\} tan^{-1}\left(\frac{b}{s+a}\right) + \frac{1}{3}\left\{b\ (s-a)^3 - b^3\ (s-a)\right\} tan^{-1}\left(\frac{b}{s-a}\right) - \frac{2}{3}\left\{b s^3 - b^3 s\right\} tan^{-1}\frac{b}{s} - \frac{25}{12} a^2 b^2 \ldots\ldots\ (6)$$

Equation (6) may be derived from the formula in the *Bulletin of the Bureau of Standards, Vol. 3, No. 1, p. 6.* Formulas (1) to (6) all assume uniform current distribution over the section of the conductors, skin effect being neglected.

*Derived from equation No. 108, *Bulletin of the Bureau of Standards,* Washington, D. C., Vol. 8, No. 1.

†"The Reactance of Strap Conductors", by H. B. Dwight, *The Electrical Review*, page 1008, June 30, 1917.

**"Skin Effect of a Return Circuit of Two Adjacent Strap Conductors", by H. B. Dwight, THE ELECTRIC JOURNAL, p. 157, April, 1916.

††*Bulletin of the Bureau of Standards,* Vol. 8, No. 1, p. 167, eq. 124, and Clerk Maxwell, Electricity and Magnetism, Vol. 11, para. 692.

The Development of Fan Motor Windings

E. W. Denman

FAN motors were wound as commutator type series motors in the earliest stage of their development. It was found that motors wound for use on a direct-current circuit could be used on single-phase alternating-current circuits, but required a much higher voltage with severe sparking occuring at the brushes. To make a series motor operate on alternating-current the reactance of the field was decreased by decreasing the number of turns in the field coils, and to get a good torque with a minimum amount of current, many armature conductors had to be used.

Fig. 1 shows the diagram of a series motor with the armature connected between the two field coils. All commutator-type motors for small fans are two pole for simplicity and low cost. The first fan motors were series motors with one coil to energize the field and a few manufacturers still make this type. For this motor one of the field coils in Fig. 1 would be omitted.

Speed control on the original series motors was obtained by shifting the brushes from the neutral position.

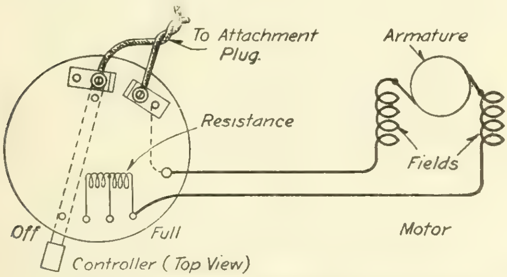


FIG. 1 SCHEMATIC DIAGRAM OF SERIES MOTOR CONNECTIONS

Later designs use resistance in series with the motor winding to lower the voltage impressed on the motor, and this lowers the speed. Taps at different points on the resistance were taken off to give the desired speed of the fan. This method of control is shown in Fig. 1, the resistance being on the controller. The first motors were provided with a ring wound armature and a punched laminated field. The laminated field was necessary as at that time practically all alternating-current circuits operated at 133 cycles, and the high iron loss in a solid pole due to the high frequency was not permissable on account of the high temperature rise.

The next step in fan motor development was an induction motor. To operate the fan near the desirable speed of 1600 r.p.m. on 133 cycles, it was necessary to have ten poles in the field. The poles were concentrated and a coil placed on alternate poles connected in series, all of the same polarity. This winding was called a consequent pole winding. The poles without coils formed a return path for the magnetic flux from the energized poles. To obtain a phase displacement of the flux in the pole, or otherwise cause a rotating effect of the flux to give a starting torque, the trailing edge of the pole was shaded; that is a band of copper was placed around a portion of the pole which retarded the flow of the flux in this section, while the flux in the remaining portion of the pole was in phase with the current in the field coils.

The rotors used in induction motors for fans have always been of the squirrel-cage type; that is if the iron were removed the copper winding would be in the form of a squirrel cage. As compared to rotors of power motors, fan motor rotors have relatively high resistance to give a reduction in speed of the fan when the flux density in the field poles is decreased. Speed change on induction fan motors is obtained by reducing the voltage impressed upon the field winding, which decreases the current and this decreases the flux density which allows a greater slip of the rotor.

To operate at 1600 r.p.m. on 60 cycles, an induction motor field should have four poles. On this and

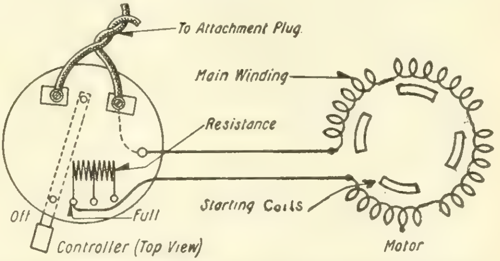


FIG. 2—INDUCTION MOTOR WITH SHADING COIL STARTING WINDING

lower frequencies solid poles cast in the main frame have been used, although this produced an excessive loss. To decrease the input and improve the characteristics a laminated field built up from punchings was developed. The same method as with the 133 cycle motors was used for starting in the earlier types of motors and is still used on some of the smaller and lower priced motors. Speed change on these motors was obtained by inserting in series with the motor field coils either resistance or a choke coil to lower the voltage on the main field. A diagram of a winding of this type is shown in Fig. 2.

With the development of the laminated field built up from sheet steel punchings with several slots per pole it was found that the winding could be distributed across the face of the pole and with the proper distribution the flux density was the greatest in the center teeth of the pole, decreasing in the outside teeth to make a quieter running motor. Fig. 3 shows a view of a distributed pole punching for an induction motor which has 24 slots. An advantage of this punching, is that it can be wound for either two poles for 25 cycles or four

poles for 60 cycles, where a four blade fan with a speed of 1400 to 1600 r.p.m. is to be used; and wound four pole on 40 cycles, and six pole on 60 cycles, where a six blade fan with a speed of 1050 r.p.m. is used. This flexibility of winding on one punching is good from the

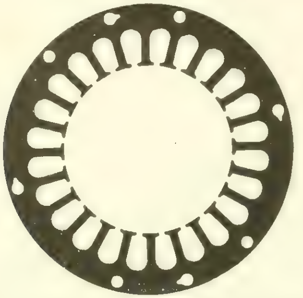
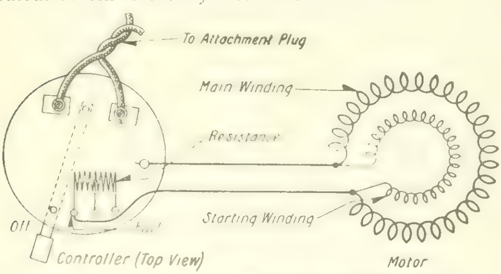


FIG. 3—INDUCTION MOTOR FIELD PUNCHING
For distributed winding.

manufacturing standpoint as it minimizes the number of dies and stock parts.

With the development of the distributed main field winding, it was found desirable to use a starting winding which was energized from the line. There are two types of this starting winding; one which remains in the circuit all the time in parallel with the main winding, as shown in Figs. 4 and 5; the other which has a cutout switch operated by the centrifugal force of weights on fingers attached to the rotor. As the rotor comes up to a predetermined speed this operation takes place. Diagrams of these windings are shown in Figs. 6 and 7.

With starting windings that remain in the circuit, the starting torque is that required to start the rotor from its static friction. For this reason as small amount of power as possible is put into the starting winding as it is in the circuit all the time when the fan is running. The total watts of the motor with this type of winding are higher than with a motor whose starting winding has a cutout switch. The starting winding with the cutout switch is usually wound to take more watts on



WINDING WITH HIGH RESISTANCE STARTING WINDING

starting than the other type, but when the rotor is up to speed this winding is open circuited and a saving results.

In the first type of starting winding as shown in Fig. 4, there are two separate windings in the motor field. The heavier or outside winding shown in the diagram is the main field, and is wound distributed in the slots of the poles, and produces the main field flux. The lighter or inside winding is distributed, with the center of the pole of this winding placed approximately one-third the pole spacing from the center of the pole of the main winding over lapping the next pole of the main winding. The total turns of the main field winding are greater than the total turns of the starting winding, therefore, the reactance is higher. The resistance of the starting winding is very high in comparison to the resistance of the main winding. The two windings are connected in parallel. The current in the starting winding is very close to being in phase with the voltage, while the current in the main winding lags due to its reactance. Since the flux of a pole is in phase with the current, the flux of the starting winding leads the flux of the main field winding and produces a rotating field, which gives a starting torque. The power input to this winding is not an entire loss as there is some torque from it at running speeds.

For controlling the speed of a fan with this type of winding, either a choke coil or resistance can be used.

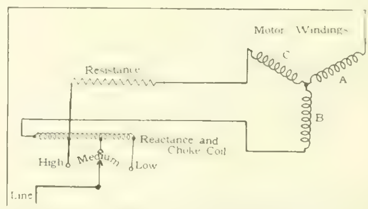


FIG. 5—SPLIT-PHASE WINDING WITH REACTANCE AND RESISTANCE

By placing either one of these in series with the motor winding the effective voltage on the motor is decreased and the current in the windings lowered. With the drop in current the flux in the field decreases and the speed changes. Resistance is usually used for manufacturing reasons and gives good performance. Most fans use two steps of resistance, making three speeds for the fan.

The fan whose diagram is shown in Fig. 5 has three windings in the motor field. These windings are connected at a common point in the motor. They are usually placed one-third the pole spacing between centers of the poles of each winding. As shown, *A* is connected to one line, *B* is connected to the other line through a choke coil or reactance, and *C* is connected to the same line as *B* except through a resistance. This reactance and resistance is proportioned so that the current flowing through the winding *A* divides between *B* and *C* in such a manner that the field flux has the rotating characteristic of a polyphase motor, thus giving a starting torque. In some motors the added resistance in winding *C* is placed in the motor winding by using a smaller size wire or a high resistance coil. Since the current in the high resistance circuit leads the current in the reactance circuit and the combined current passes

through A, the flux of the winding C leads the flux of winding A and the flux in winding A leads that in winding B, thus the direction of rotor travel is from C to A.

Speed regulation with a winding of this type is usually obtained by having more turns in the choke coil, which is in series with winding B, than are needed for the reactance necessary for the performance at high

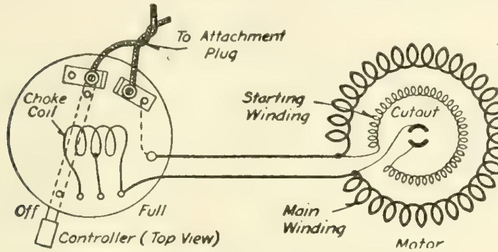


FIG. 6—SPLIT-PHASE MOTOR WITH CUT OUT SWITCH IN THE STARTING WINDING

speed. Taps in these added turns are arranged so that they can be placed in series with the total winding of the motor including the resistance and reactance. This lowers the voltage on the motor and the effect is a decrease in speed of the fan.

The simplest winding with a cutout switch in the starting winding is shown in Fig. 6. The main winding is of heavy wire wound distributed and when the fan is running at its running speed this winding carries the load. The center of the starting winding pole is placed between the poles of the main winding and overlapping half of a pole on each side. The starting winding can be wound either distributed or concentrated as it makes but little difference in its performance, it being open circuited when the motor is running.

To decrease the speed of the fan with a motor wound with the above windings a choke coil is used. The starting current when the motor is connected to the line is several times higher than the running current, and if resistance were used for speed control the

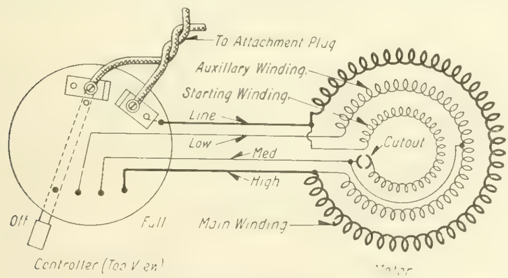


FIG. 7—SPLIT-PHASE MOTOR WITH A SPEED CHANGING WINDING ADDED TO THE MAIN WINDING

drop over this would be so great that the motor could not pull the fan up to the cutout speed of the starting switch. The choke coil is operated at a point where the iron is saturated and the increase of current at starting increases the voltage drop on the choke coils only a little above that at running conditions. This allows the motor to pull the fan up beyond the cutout speed of the starting switch. Here the torque of the main winding is less than when the full voltage is on the motor winding and the fan runs at the lower speed.

Fig. 7 shows a desk fan winding diagram similar to that shown in Fig. 6 except that for speed change the motor winding has taps in the main coils. The high speed point is where there are the fewest turns in the field. Here the field flux is greatest and the torque and speed high. To lower the speed more turns are connected in the main winding. This decreases the flux and causes a decrease in speed, the change in connection being made by the contact lever in the base. The starting winding operates the same as that in Fig. 6. The advantage of this winding is in the reduction of the input to the motor on low speeds, there being no choke coil loss. Also a greater speed reduction can be obtained.

The development of the windings for ceiling fans has been along the same lines as the desk fan. The speed of the ceiling fan is slow compared to that of the desk fan and for alternating-current motors they are

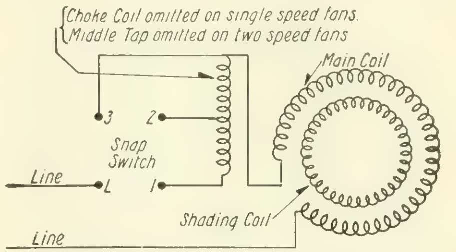


FIG. 8—CEILING FAN MOTOR WITH INSULATED SHADING COIL STARTING WINDING

wound with a greater number of poles. The principal winding used has the shading coil start, it being difficult to operate a centrifugal switch at such low speeds. Some motors have copper band shading coils over a portion of the pole, similar to the desk fan in Fig. 2. Others use a shading coil of heavy flexible wire threaded through the slots on top of the primary or main winding with the ends soldered together forming a short-circuited winding, as shown in Fig. 7. The starting winding is insulated before being put in, so that it does not ground the main winding. It produces the same shading in all the poles, making a quiet running motor. Speed regulation is obtained by using a choke coil in series with the main winding.

Along with the development of the induction motor for fans on alternating-current circuits the series motor has had equal attention for both alternating and direct-current, although the changes have not been so marked in the windings. The slotted armature punching for the drum type armature makes a much better rotor than the ring type. Cast-iron field frames with solid cast poles were used for direct-current motors. To make a series type motor with a frame that could be used for either alternating or direct current, a laminated field was developed in combination with the armature punch-

ing. With this field and armature built up from punchings, the motor can be used on low frequencies to a better advantage than an induction motor, due to the speeds necessitated by a two-pole induction motor. The development of windings for series motors, since the use of the punched field and armature, has been in determining the proper field and armature turns to use on the different frequencies to give the best performance and highest efficiencies.

The latest development in induction fan motor windings has been a winding with a high starting torque, high efficiency at running speeds, without a cutout switch and with a large speed reduction. A diagram of this winding is shown in Fig. 9. The motor winding is the same as shown in Fig. 6 except that the cutout switch is omitted and the lead from the starting winding to the cutout switch is brought out of the motor to the base, making three leads from the motor body to the base. In the base of the motor is a transformer, the primary winding of which is in series with the main winding of the motor, the secondary being connected across the starting winding. The characteristics of the transformer are similar to those of a series transformer with reactance in its secondary circuit. When the motor with this complete winding is thrown on the line, the current through the main winding passes through the primary of the transformer and the secondary voltage induced is impressed on the starting winding of the motor. The lag of the voltage of the secondary behind the main current in the primary, plus the lag caused due to the reactance of the starting winding causes a large phase angle between the currents in the main and starting winding in the motor fields. It has been found by test that the angle between these two currents on starting, with the proper design of the transformer, approaches 90 electrical degrees. This gives the effect of a two-phase motor on starting. In running, the angle changes slightly but always remains of a value to assist the main winding.

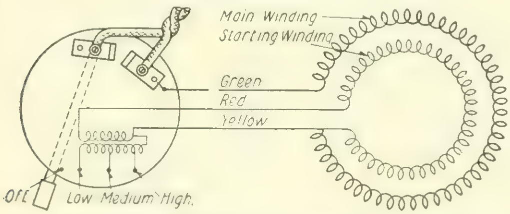


FIG. 9—SPLIT-PHASE WINDING WITH SERIES TRANSFORMER
For shifting the phase of the starting winding and improving the speed control.

To lower the speed of the fan more turns are placed in the primary of the transformer. This has the effect of adding reactance in series with the motor main winding to reduce the flux density in the motor field. Also since the iron in the transformer is worked at a high density, the added turns in its primary with the decrease of primary current have the effect of keeping the secondary voltage of the transformer approximately constant. This makes possible a high starting torque at low speed and consequently a much greater speed change than could otherwise be obtained.

The curves, Fig. 10, show the running and starting characteristics of a motor wound with a winding of this type. Curve *A* is taken on the main winding of the motor only, the starting winding being open circuited. Curve *B* is taken on the same motor, connected as in Fig. 9, with the main winding in series with the primary winding of the transformer and in the high-speed position. Curve *C* is taken on the same motor with more turns in the primary of the transformer, or middle-speed connection for the fan. Curve *D* is taken on the same motor with maximum turns in the primary of the transformer for low speed of the fan. Curve *E* is the speed-torque curve of a fan. Curves *A* and *B* coincide from the no-load or zero torque point to the point of pull out *X*. From this point on the lower side of the curves, the torque of curve *A* drops off very rapidly with a slight decrease in speed and at zero speed there is no torque. This is the characteristic of a single-phase motor without some starting or phase splitting

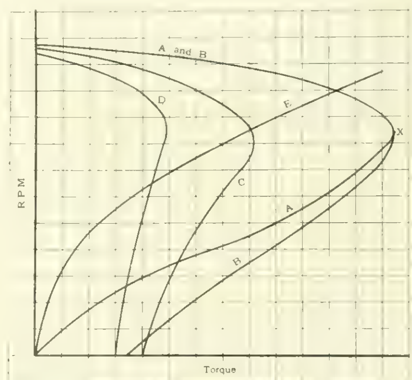


FIG. 10—CHARACTERISTICS OF WINDING SHOWN IN FIG. 9

device. On curve *B* the torque does not fall so fast with a drop in speed and at zero speed there is a positive amount of torque. This is known as the starting torque on this motor with the high-speed connection. Curves *C* and *D* are lower than the curve *B* but have the same characteristic shape. Curve *E* is the torque of the fan and the points where this curve crosses the other curves will be the speeds at which the motor will drive the fan with the respective connections on the transformer.

The advantages of this winding are:—the large amount of speed reduction, reduction of the watts input with the reduction of speed, high-starting torque and a quiet running motor on single phase. The amount of speed reduction is from 25 to 100 percent more than with any other type of fan motor winding. The reduction of watts input with the reduction of speed is nearly proportional. The high starting torque on all speeds eliminates trouble from burnouts on low voltage. This motor with its approximate polyphase winding is also quieter than a straight single-phase motor.

Large Capacity Circuit Breakers

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THE erection and equipment of large, heavy capacity power plants involves many and varied problems, requiring the service of a small army of experts to assemble and adjust the numerous complicated units which go to make up the modern power station. The generating units require the service of both mechanical and electrical experts; other of the electrical devices require expert mechanics to put them into proper operating condition. The wiring of the switchboard and control boards is usually so laid out that, by following a completely detailed diagram, wiremen of ordinary skill can assemble this part of the equipment.

The bus structure and circuit breaker compartments are presumably of such a nature that masons and concrete workers can erect a satisfactory structure.

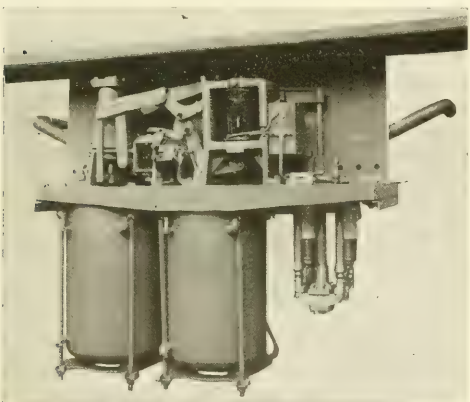

FIG. 1—WESTINGHOUSE 15 000 VOLT, 1600 AMPERE TYPE CO CIRCUIT BREAKER
Of 23 000 arc amperes interrupting capacity.

Some of the large modern circuit breakers, however, involve quite an elaborate structure and require that dimensions be adhered to very closely and also that separate mechanical units be quite accurately built into the masonry. Such accuracy is beyond the skill of ordinary masons and requires the service of high class mechanics, adding very materially to the cost of the installation.

Having in mind the very large saving to the erector, both in time and expense which could be effected by a self-contained design of circuit breaker which should leave the factory fully assembled and realizing also the imperative demand for economy of space, a circuit breaker has been developed which embodies these two features to an extent not heretofore realized in any large capacity, high powered circuit breaker.

This circuit breaker, Fig. 1, embodies the most up-to-date features of design. The entire circuit breaker is built on a single heavy steel frame, the operating mechanism,—closing solenoid toggle levers, trip mechanism, accelerator and magnet cut-off device being located on the fore part of the top of the frame. The levers come into the circuit breaker in the rear of the operating mechanism, passing through the base into the oil tanks suspended beneath. The oil tanks are cylindrical in form with round bottoms and are pressed from a single piece without seams. Heavy tie bolts and steel cradles suspend the tanks directly from the steel frame.

The operating mechanism is of the simplest possible form with the number of parts reduced to the

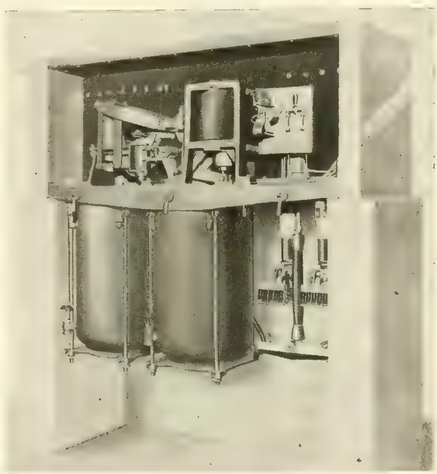

FIG. 2—THREE THOUSAND AMPERE CIRCUIT BREAKER
Of same voltage and breaking capacity rating as Fig. 1.

minimum consistent with a proper functioning of the complete unit. A solenoid furnishes power for closing the mechanism through toggle levers, and links are so arranged as to give practically a straight line vertical motion to the cross arm carrying the three moving contact elements. A positive latch holds the mechanism closed. The latch is released by a trip solenoid and the mechanism drops to the open position, a heavy accelerating spring assisting gravity in imparting to the moving element the high speed of opening essential to a successful circuit interrupting device. A dashpot placed in the same cylinder with the accelerating spring decelerates the moving element and brings it to rest without undue shock at the end of the opening movement. A dashpot in the closing solenoid forms a

cushion for the closing movement and absorbs the shock. A magnetic blowout cut-off device opens the circuit of the closing solenoid at the instant the circuit breaker is latched closed. The current of the closing solenoid is therefore controlled entirely at the circuit breaker and only a light control circuit is run to the operating board. The cut-off device also has a lock out feature, preventing repeating should automatic tripping occur immediately upon closing the circuit breaker. The rapid action of this cut-off device also prevents the current in the solenoid from reaching the value indicated by the ohmic resistance of the coil. The counter e.m.f. due to the motion of the plunger opposes the flow of current in the coil and the cut-off switch opens the coil circuit before the current builds up to the maximum value it would reach if the circuit were not opened so quickly.

The circuit breaker leads are continuously insulated copper rods which come into the circuit breaker in the rear of the mechanism and are separated from the mechanism by barriers. The leads of adjacent poles are also separated by barriers, isolating the leads of each phase of the circuit in individual compartments. The leads of each phase may be arranged side by side in the same horizontal plane or may be one above the other in a vertical plane as best suits the installation.

The contacts may be of the butt brush form or of the finger form as best suited to the conditions. The stationary members are carried on the lower end of the terminal rods. These rods are insulated where they pass through the circuit breaker frame by heavy porcelain bushings which also support the rods and take the thrust of the moving member against the stationary contact members. The contact surfaces proper are well down in the oil, assuring ample head of oil over the contacts at all times. The arcing contacts are so designed as to maintain contact until the moving element has attained a high rate of acceleration, thus affording a quick break and large main contact opening at the time of actual circuit interrupting. They are also placed so as to give the maximum distance from the tank sides and free escape for arc gases. An insulating lining is provided inside the tank as a mechanical barrier, reducing the oil agitation at the contacts to a minimum.

Particular attention has been given to mechanical stability of the contact details with a view of preventing any distortion under the strains of magnetic force incident to the enormous currents which may flow during the first few cycles before the circuit breaker opens on short-circuit. The ample design of contact details, both in contact area and in cross-section of conducting parts and the heavy contact pressure insured by the rugged operating mechanism afford large thermal capacity and reduce the tendency of the contacts to fuse under the heavy currents. Provision is made for the dissipation of the arc gases through suitably arranged vents. These are designed to close upon the occurrence of pressure within the tank thus preventing the expulsion of oil. When the disturbance has subsided, the vents open and a draft is created through the expansion chamber which removes the residue of the arc gases, as well as the ordinary vapor which forms above a body of oil exposed to the atmosphere.

The internal control wiring for solenoids, cut-off devices and indicating devices is complete, and the connections all indicated plainly to correspond with the wiring drawing.

The illustrations give an idea of the compactness and economy of space inherent in these circuit breakers. The expedient of bringing the terminal rods into the circuit breaker in the same plane which the mechanism occupies, effects the greatest saving and at no sacrifice in efficiency. The separation of the leads into compartments containing nothing but these insulated conductors and into which no gases can vent is a valuable asset from an insulation standpoint, while their complete isolation from the operating mechanism makes the arrangement ideal from a safety-first view point.

The simplicity of cell construction is shown by Fig. 2. The rectangular compartment with the plain bushings through the rear wall for the terminal rods is prepared, and the complete circuit breaker as received from the factory is slipped into place and the frame bolted to the four supporting cleats set in the masonry. Connections are made, an inspection made of all parts to see that nothing has been damaged in transit, the oil tanks filled and the circuit breaker is ready for service.

The features of easy installation, simple mechanism, rugged construction, maximum of circuit interrupting capacity in minimum of space, and ideal safety-first isolation of live high-tension parts makes this type of unit well adapted to meet the requirements of heavy circuit breaker practice.

The Electrically-Operated Gyratory Riddle

C. A. M. Weber

THE application of the small industrial motor to the foundry riddle is another one of the many electrically-operated labor saving schemes which have come into the market in recent years.

The foundry riddle is used not only to sift but also to mix the sand in the process of tempering. Heretofore this has been done by hand riddles and inclined screens. These were not only slow but more or less difficult of operation and required a certain amount of skill in order to thoroughly mix the sand. The first improvement over hand operation in sifting and mixing foundry sand was the application of the steam or gas engine which was arranged to impart a reciprocating motion to a horizontally mounted screen which was kept full of sand by one or more workman shoveling. This eliminated the hand sifting and was considered quite a success, but aside from the disadvantage of being cumbersome it only sifted the sand and did not mix it. The disadvantage of sifting without thoroughly mixing lies in the fact that the sand must be sifted oftener which entails additional expense for labor. However, the steam or gas driven screen was a labor saving device as compared with the hand methods formerly used and designers began to develop power operated foundry riddles which were less cumbersome and more portable than the original power driven foundry riddles.

FIG. 1—A 20 INCH CIRCULAR RIDDLE
Driven by a 1-6 hp, 850 r.p.m. motor.

The first step in this direction was to apply the electric motor, changing its motion from rotation to reciprocation in order to obtain the same effect as when the outfit was driven by line shafting. For a number of years the development of the electrically-driven foundry riddle remained practically at a standstill due mainly to designers trying to utilize the reciprocating principle, until riddles using a circular motion were developed.

In hand operation the riddle not only sifts the sand but thoroughly mixes it as well. This is due to the circular or gyratory motion given to the riddle when hand operated and it is the utilization of this gyratory motion that makes the riddle herewith illustrated so very successful.

FIG. 2—A 24 INCH SQUARE RIDDLE
Driven by a ⅛ hp, 1725 r.p.m. motor.

In the main, the design consists of building the complete outfit including motor, riddle, etc., to be suspended from a point. The motor is mounted near the top and imparts rotary motion to a vertical shaft which revolves an unbalanced fly wheel in a horizontal plane. At the lower extremity of the outfit is mounted the usual design of riddle.

By having the complete outfit suspended from a point and the lower extremity free to move, the revolving unbalanced flywheel tends to rotate about its center of gravity and in doing so moves the entire frame work of the outfit in circular motion about its center of

gravity thereby imparting to the riddle the same kind of motion which is obtained in hand riddling. The lower extremity of the complete outfit gyrates in the largest circle and the motor being mounted at the top gyrates in a circle of very small diameter.

The gyratory riddle shown in Fig. 1 is driven by a direct connected 1/6 horse-power 850 r.p.m. motor, either alternating or direct-current depending upon the supply available. The diameter of the riddle is 20 inches. The riddle shown in Fig. 2 is larger but works on the same principle as the smaller size, a 24 inch square riddle being used. The motor in this design is one-third horse-power 1725 r.p.m. and is connected to the unbalanced fly wheel shaft through a worm and worm wheel with a 7 to 1 reduction.

The size and speed of the unbalanced flywheel have been so proportioned as to cause the riddle in Fig. 1 to gyrate approximately three-fourths of an inch and the riddle in Fig. 2 approximately two inches.

Since the gyratory riddle is suspended from a point it is extremely portable. All that is necessary is to place suitable hooks at desired points or stretch a cable and the riddle can be moved from place to place. There are no legs to get into the way of shovels or wheelbarrows and the riddle may be used equally as well over a flask as between flasks or at some more remote point. In the case of the riddle shown in Fig. 2 two wheelbarrows may be used, one to take the screened sand and the other the refuse.

The cost of operating one of these electrically operated gyratory foundry riddles is practically negligible as compared with the saving effected. In making estimates on the cost of operation it should be borne in mind that the expense of operation is incurred only while the outfit is in use; for when not in use it is shut down and in that respect is quite unlike the line shaft outfits, where the line shaft expense goes on during the entire day.

Methods of Testing for Hardness

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Research Engineering Dept.,
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HARDNESS has been defined as "resistance to permanent deformation." There are, however, various kinds of hardness depending upon the stress applied to the material. Among these may be mentioned cutting hardness, elastic hardness, tensile hardness and abrasion hardness. Many methods have been devised for measuring these properties. It is evident that the results obtained by two different methods cannot properly be compared unless the same kind of hardness is being tested.

MOH SCALE OF HARDNESS

One of the earliest methods of comparing hardness of two materials was to scratch one specimen against the other, the specimen which would make a clean scratch upon the other being taken as the harder of the two. The Moh scale of hardness, intended especially for minerals, is based upon this principle. This is a crude test and gives an indication of surface hardness only. The Moh scale of hardness is based on the principle that the harder of two minerals will scratch the other and will not be scratched by it. In order of increasing hardness, the scale is as follows:

1—Talc	6—Orthoclase
2—Gypsum	7—Quartz
3—Calcite	8—Topaz
4—Fluorspar	9—Corundum
5—Apatite	10—Diamond

SCLEROMETER TEST

The sclerometer, which was invented about 100 years ago, and was developed in 1886 by Prof. Turner and others, measures hardness by scratching a polished surface with a diamond point. There are several methods of using this apparatus. By one method, the weight required to make a barely visible scratch determines the degree of hardness. When used with constant pressure, the depth of the cut indicates hardness. When used with constant depth of cut, the weight required is the measure of the hardness.

BAUER DRILL TEST

The Bauer drill test (sometimes known as Keep's test, after the manufacturer of the machine) gives an indication of cutting hardness, to determine the machinability of metals. It therefore depends upon the hardness, toughness and abrasiveness of the metal under test. The machine consists essentially of a fluted drill driven at constant speed and held against the test specimen by a definite pressure, a support for the metal to be tested, and an autographic attachment which traces a curve indicating the depth of the hole as ordinates and the number of revolutions of the drill as abscissæ. It is necessary to have the drill sharpened so that the rake and clearance are the same for each test. The drill must be kept sharp; dullness of the drill becomes evident from the change in the slope of the curve. The hardness numeral is taken as the tangent of the angle which the curve makes with the vertical axis.

This test has its limitations as, in order to compare the hardness of two metals, the drill must be of uniform quality, run at the same speed and at the same pressure. But in order to obtain the best results with a metal, the speed of the drill should be adapted to that metal and any comparison at a different speed may not be a fair one. It is especially well adapted for determining the machining qualities of cast iron.

CONE TEST

Ludwik proposed the use of a cone having a 90 degree angular opening. He measured the depth of in-

dentation and calculated the hardness numeral on the basis of the entire applied pressure divided by the area of the conical indentation. The relation between load and depth of indentation is parabolic, the hardness numeral decreasing rapidly with increasing loads, and becoming approximately constant at high loads. This interferes with the classifying of the metals in a relative hardness scale. Another objection to the cone is the tendency of the point to become flattened under pressure.

BRINELL TEST

As an improvement on the cone test, Brinell suggested the use of a hardened steel ball instead of the

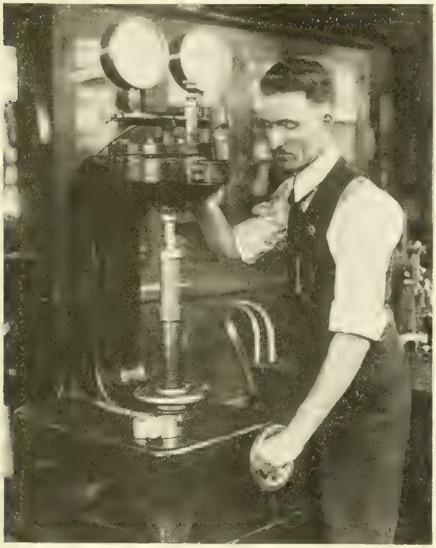


FIG. 1—BRINELL HYDRAULIC TYPE TESTING MACHINE

cone. In the Brinell hardness test a hardened steel ball is pressed into the flat surface of the material to be tested by means of a known pressure. The Brinell hardness number is obtained by dividing the pressure by the area of the curved surface of indentation and may be calculated from the formula:—

$$N = \frac{P}{2\pi t R}$$

Where N = hardness number, P = pressure, t = depth of indentation and R = radius of curvature of indentation = radius of ball.

As the diameter of the indentation can usually be more readily measured than the depth, the following formula is more commonly used:—

$$N = \frac{P}{2\pi R\left[R - \sqrt{R^2 - \left(\frac{D}{2}\right)^2}\right]}$$

where D is the diameter of indentation and the other symbols are the same as indicated above.

The American Society for Testing Materials recommends the use of a ball 10 mm. in diameter, and a pressure of 3000 kg for steel or 500 kg for soft metals, applied for at least 30 seconds. The hardness number obtained from the formula will vary somewhat with different pressures and different sizes of ball.

In order to obtain sufficient accuracy, the diameter of indentation is measured by means of a magnifying glass which has a millimeter scale in the field. Two measurements of an indentation are made at right angles to each other and the average taken to determine the hardness. The hardness numbers corresponding to the various diameters of impression for 500 and 3000 kg. pressure are given in Table I.

Two types of machine are used in making Brinell tests; the hydraulic type and the lever type. In the hydraulic type, Fig. 1, the ball is held in the hydraulically-operated piston which moves downward. The piston is a close fit within the cylinders, and does not require packing. Pressure is applied by means of a small hand pump, and is indicated in kilograms by a gage. In some machines a system of dead weights is so ap-

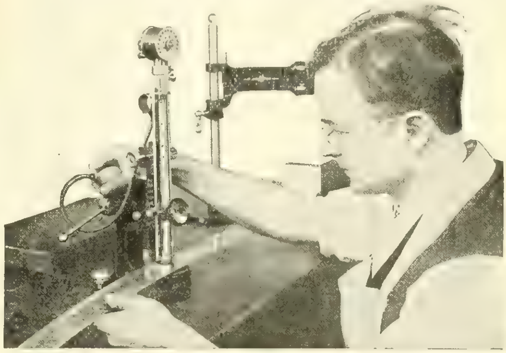


FIG. 2—SCLEROSCOPE

plied that the pressure cannot exceed that required for the test.

In the lever type machine, the ball is held stationary and the specimen is moved up against the ball by a screw operated by a crank. The pressure is weighed through a system of levers. The poise is set to the desired pressure and when this is obtained the beam rises.

The Brinell test cannot be used satisfactorily when the test specimen is too thin, as the hardness of the base supporting the specimen will influence the size of indentation and therefore the hardness number. It should not be made so near the edge as to affect the diameter of indentation. It is not applicable to brittle materials which crack when tested, nor to steels which are hard enough to cause permanent deformation of the steel ball.

The following are a few characteristic applications of the Brinell test:—

1—To determine the effect of annealing or hardening of steel parts. For example, larger heat treated gears and pinions.

2—To determine the degree of uniformity of hardness of heat treated steel parts.

3—To measure the hardness of babbitt metals as an indication of composition and proper manufacturing methods.

4—To determine the relative hardness of materials.

SCLEROSCOPE TEST

The scleroscope, which was invented by Mr. A. F. Shore, measures the hardness of a material by the rebound of a small weight dropped upon the specimen from a definite height. It consists essentially of a cylindrical weight about 0.25 inches in diameter by 0.75 inches long, with a blunt diamond tip about 0.020 inches in diameter, which falls by its own weight a distance of 10 inches inside a vertical glass tube upon the test specimen. The weight makes a small indentation on the specimen, and the height of rebound gives a measure of the work done by the weight upon the specimen and therefore measures the hardness of the specimen. The vertical glass tube is marked with an arbitrary scale, divided into 100 units, a hardness of 100 being taken as the average hardness of martensitic high carbon steel.

When the bulb is pressed, the weight is drawn up by suction, and held by hooks at the top of the glass tube. When the bulb is pressed again the weight is released and air is admitted to the tube above the weight so that it will fall freely. The weight does not remain at the highest point of rebound so this point must be noted before the weight falls. A magnifying glass, which can be set at the proper height, enables accurate readings to be taken. The specimen should be supported in such a manner as to avoid any spring as this would give a fictitious value for the hardness. The instrument should be so adjusted that the rebound will be at right angles to the surface of the specimen. The base is removable so that the scleroscope may be used to measure the hardness of large pieces which could not be placed in the instrument in its usual form.

APPLICATIONS

The scleroscope is especially well adapted to indicate the surface hardness of very hard materials, such as tool steels or case hardened steel. With very soft materials, the rebound of the weight is so slight that accurate readings cannot be taken, the percentage of error being much greater than with hard materials. It is a valuable test, as it can be made quickly at low cost without destroying the material tested, thus allowing tests to be made upon either the raw material or the finished product.

The hardness factors for different materials are not comparable as the rebound of the weight is dependent upon the elasticity of the material. For instance, the scleroscope factor for soft rubber is sometimes as large as for steel, although these materials are widely different in hardness and strength.

The Brinell test provides a measure of the hardness not only at the surface but for an appreciable distance below the surface of the specimen.

While there may be a relation between the scleroscope and Brinell hardness numbers and the ultimate tensile strength and elastic limit of the material, this relation varies with different materials. It would therefore not be correct to use the same factor for calculating the tensile strength of different steels from their hardness number, as the ratio varies considerably with the chemical composition, mechanical working and heat treatment.

Probably their greatest usefulness occurs in making check tests to determine the condition of the material tested, when this material is known to be of a certain type and is supposed to have received certain treatment. For instance; the scleroscope is used to determine whether tool steels have been given the proper heat treatment. With the characteristics of the material determined by means of the chemical analysis, and physical tests, and their relation to the hardness test known, the hardness test is used as a check to insure uniformity of the material.

The scleroscope and Brinell tests are perhaps the most widely used hardness tests. Each has its field within which it is most effective. The advantages and limitations of the various test methods should be considered in selecting a test for a given application.

TABLE I—BRINELL HARDNESS NUMBERS

Dia. of Imp.	Brinell No.		Dia. of Imp.	Brinell No.		Dia. of Imp.	Brinell No.		Dia. of Imp.	Brinell No.		Dia. of Imp.	Brinell No.		Dia. of Imp.	Brinell No.		Dia. of Imp.	Brinell No.		Dia. of Imp.	Brinell No.		Dia. of Imp.	Brinell No.	
	500	3000		500	3000		500	3000		500	3000		500	3000		500	3000		500	3000		500	3000		500	3000
1.00	636.7	3820	2.00	157.6	946	3.00	69.1	414.7	4.00	38.1	228.7	5.00	23.8	142.5	6.00	15.9	95.5	7.00	11.1	66.8	8.00	8.0	47.8	9.00	5.6	33.8
1.05	576.1	3457	2.05	150.0	900	3.05	66.8	400.9	4.05	37.1	222.8	5.05	23.3	139.5	6.05	15.6	93.7	7.05	11.0	65.7	8.05	7.8	47.0	9.05	5.5	33.2
1.10	524.4	3146	2.10	142.7	856	3.10	64.6	387.7	4.10	36.2	217.3	5.10	22.8	136.3	6.10	15.3	92.0	7.10	10.8	64.6	8.10	7.7	46.2	9.10	5.4	32.6
1.15	487.8	2927	2.15	136.0	816	3.15	62.5	375.0	4.15	35.3	211.7	5.15	22.3	133.7	6.15	15.1	90.3	7.15	10.6	63.5	8.15	7.6	45.4	9.15	5.3	32.0
1.20	437.5	2625	2.20	129.9	779	3.20	60.5	363.1	4.20	34.4	206.5	5.20	21.8	131.0	6.20	14.8	88.7	7.20	10.4	62.4	8.20	7.4	44.6	9.20	5.2	31.4
1.25	406.8	2441	2.25	124.1	744.6	3.25	58.6	351.7	4.25	33.6	201.5	5.25	21.4	128.3	6.25	14.5	87.1	7.25	10.2	61.4	8.25	7.3	43.9	9.25	5.1	30.8
1.30	375.4	2252	2.30	118.8	712.8	3.30	56.8	341.0	4.30	32.8	196.5	5.30	20.9	125.6	6.30	14.3	85.5	7.20	10.1	60.4	8.30	7.2	43.2	9.30	5.0	30.2
1.35	347.1	2083	2.35	113.6	681.6	3.35	55.1	330.4	4.35	32.0	191.9	5.35	20.5	123.1	6.35	14.0	83.9	7.35	9.9	59.4	8.35	7.1	42.5	9.35	4.9	29.6
1.40	323.2	1939	2.40	108.9	653.4	3.40	53.4	320.5	4.40	31.2	187.3	5.40	20.1	120.7	6.40	13.7	82.4	7.40	9.7	58.4	8.40	7.0	41.8	9.40	4.8	29.0
1.45	301.2	1807	2.45	104.5	627.0	3.45	51.8	311.0	4.45	30.5	182.3	5.45	19.7	118.2	6.45	13.5	81.0	7.45	9.6	57.4	8.45	6.8	41.1	9.45	4.7	28.4
1.50	281.7	1690	2.50	100.2	601.3	3.50	50.3	301.9	4.50	29.8	178.5	5.50	19.3	115.9	6.50	13.3	79.6	7.50	9.4	56.4	8.50	6.7	40.4	9.50	4.6	27.8
1.55	263.5	1581	2.55	96.3	579.7	3.55	48.9	293.2	4.55	29.1	174.4	5.55	18.9	113.5	6.55	13.0	78.2	7.55	9.3	55.5	8.55	6.6	39.7	9.55	4.5	27.2
1.60	247.1	1483	2.60	92.5	555.2	3.60	47.5	284.8	4.60	28.4	170.3	5.60	18.6	111.4	6.60	12.8	76.8	7.60	9.1	54.5	8.60	6.5	39.9	9.60	4.4	26.5
1.65	232.0	1392	2.65	89.0	534.0	3.65	46.1	276.8	4.65	27.8	166.5	5.65	18.2	109.2	6.65	12.6	75.5	7.65	8.9	53.6	8.65	6.4	38.3	9.65	4.3	25.9
1.70	218.6	1312	2.70	85.9	515.3	3.70	44.8	269.0	4.70	27.1	162.7	5.70	17.9	107.1	6.70	12.4	74.1	7.70	8.8	52.7	8.70	6.3	37.7	9.70	4.2	25.3
1.75	206.2	1237	2.75	82.6	495.3	3.75	43.6	261.6	4.75	26.5	159.2	5.75	17.5	105.0	6.75	12.1	72.8	7.75	8.7	51.9	8.75	6.2	37.0	9.75	4.1	24.5
1.80	195.0	1170	2.80	79.6	477.5	3.80	42.4	254.6	4.80	25.9	155.6	5.80	17.2	103.0	6.80	11.9	71.6	7.80	8.5	51.1	8.80	6.1	36.4	9.80	4.0	23.8
1.85	184.4	1106	2.85	76.7	460.4	3.85	41.3	247.9	4.85	25.4	152.2	5.85	16.9	101.1	6.85	11.7	70.4	7.85	8.4	50.2	8.85	6.0	35.8	9.85	3.9	23.1
1.90	174.5	1047	2.90	74.1	444.5	3.90	40.2	241.1	4.90	24.8	148.9	5.90	16.5	99.2	6.90	11.5	69.2	7.90	8.2	49.4	8.90	5.9	35.1	9.90	3.7	22.3
1.95	165.8	995	2.95	71.5	429.2	3.95	39.2	234.9	4.95	24.3	145.7	5.95	16.2	97.2	6.95	11.3	68.0	7.95	8.1	48.6	8.95	5.8	34.5	9.95	3.5	21.2

With the 3000 kilogram pressure and 10 millimeter ball, the pressure is left on for 15 seconds; with the 500 kilogram pressure and 10 millimeter ball, the pressure is left on for 30 seconds. The following readings are typical: high carbon steel, 641; tool steel, 289; Bessemer steel, 188; manganese steel, 179; cast iron, 160; copper, 89.5.

The Essentials of Transformer Practice—XXIII

Parallel Operation

E. G. Reed

THE PARALLEL operation of two or more transformers implies their being connected to carry the load jointly, so that an individual unit may be added to or taken away from the group with no other effect than decreasing or increasing the load on the remaining transformers. The measure of the satisfactory parallel operation of a number of transformers is the manner in which they divide the common load. If the individual units have the same rating they should share the load equally, and if they are different in rating, the load taken by each should be proportional to its rating.

In order that two transformers may operate satisfactorily in parallel, their secondary voltages must be in time-phase relation and equal in value. These conditions are established at no-load, if the polarity and voltage ratios of the transformers are the same. Another way of looking at this matter is to think of the secondary windings connected in parallel as a series circuit. Satisfactory parallel operation will be established, if there is no tendency to establish a current in this series

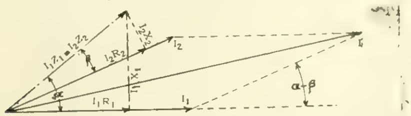


FIG. 1—PHASE RELATIONS OF THE LOAD CURRENTS AND THE VOLTAGE DROPS IN TWO TRANSFORMERS CONNECTED IN PARALLEL

circuit; which will be when the voltage of one winding is equal and in time-phase opposition to that of the other. If the voltages were not in time phase opposition, a large current would flow between the transformers which would be in effect a short-circuit on both units. Under load conditions, the division of the load depends upon the relative regulation characteristics of the transformers.

DIVISION OF LOAD IN TRANSFORMERS CONNECTED IN PARALLEL

When connected in parallel, two transformers having the same polarity and ratio of transformation will divide the common load between them, in such proportion that the impedance drop across each is the same. If the impedance drop across the first transformer is I_1Z_1 and across the second I_2Z_2, this relation may be expressed as follows,—

$$I_1 Z_1 = I_2 Z_2 \qquad (1)$$

and is shown graphically in Fig. 1. The impedance of transformers is usually specified in percent impedance volts, rather than in ohms, so that the following relations are developed with this fact in view. By definition, the percent impedance of the first transformer is,—

$$\text{Percent } Z_1 = \frac{(I_1 \text{ normal})\ Z_1}{E} \qquad (2)$$

Where $(I_1$ *normal*) and E are the normal current and voltage of the transformer. Similarly for the second transformer,—

$$\text{Percent } Z_2 = \frac{(I_2 \text{ normal})\ Z_2}{E} \qquad (3)$$

Substituting the values of Z_1 and Z_2 from equation *2* and *3* in equation *1*, gives,—

$$\frac{I_1}{I_2} = \frac{(I_1 \text{ normal}) \text{ percent } Z_2}{(I_2 \text{ normal}) \text{ percent } Z_1}$$

Multiplying through by E, gives,—

$$\frac{(k.v.a.)_1}{(k.v.a.)_2} = \frac{(K.V.A.)_1\ \%\ Z_2}{(K.V.A.)_2\ \%\ Z_1} \qquad (4)$$

in which *k.v.a.* represents the load and *K.V.A.* the transformer rating.

In Fig. 1 the current I_1 and the voltage drop $I_1 R_1$ are in phase, as also are the current I_2 and the voltage drop $I_2 R_2$. The resistances R_1 and R_2 are the resist-

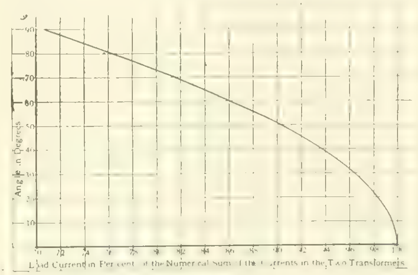


FIG. 2—CURVE SHOWING HOW THE VECTOR SUM OF THE CURRENTS IN THE TWO TRANSFORMERS CONNECTED IN PARALLEL COMPARES TO THE NUMERICAL SUM

With variable phase angle between the currents.

ances of the first and second transformers respectively. The total current I is the vector sum of the currents I_1 and I_2, that is,—

$$I = I_1 + I_2$$

or,

$$I = I_1 + I_2 \cos(\alpha - \beta) + j I_2 \sin(\alpha - \beta)$$

Multiplying through by E, gives,—

$$k.v.a. = (k.v.a.)_1 + (k.v.a.)_2 \cos(\alpha - \beta) + j (k.v.a.)_2 \sin(\alpha - \beta)$$

Substituting value of $k.v.a._2$ from equation *4*, gives,—

$$(k.v.a.)_1 = \frac{k.v.a.}{1 + \frac{(K.V.A.)_2\,\%\,Z_1}{(K.V.A.)_1\,\%\,Z_2}\cos(\alpha - \beta) + j\,\frac{(K.V.A.)_2\,\%\,Z_1}{(K.V.A.)_1\,\%\,Z_2}\sin(\alpha - \beta)} \qquad (5)$$

Similarly,—

$$(k.v.a.)_2 = \frac{k.v.a.}{1 + \frac{(K.V.A.)_1\,\%\,Z_2}{(K.V.A.)_2\,\%\,Z_1}\cos(\alpha - \beta) + j\,\frac{(K.V.A.)_1\,\%\,Z_2}{(K.V.A.)_2\,\%\,Z_1}\sin(\alpha - \beta)} \qquad (6)$$

In using these equations in a particular case it is convenient to use the relations,—

$$\cos(\alpha - \beta) = \cos\alpha \cos\beta + \sin\alpha \sin\beta$$

or,—

$$\cos(\alpha - \beta) = \frac{R_1}{Z_1}\frac{R_2}{Z_2} + \frac{X_1}{Z_1}\frac{X_2}{Z_2}$$

which has the same value as,—

$$\frac{(\%\,copper\ loss)_1\,(\%\,copper\ loss)_2 + (\%\,reactance)_1\,(\%\,reactance)_2}{\%\,Z_1\ \%\,Z_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

It is evident from equation 7, that if the first transformer has zero resistance, and the second transformer has zero reactance, that the cosine of the phase angle between the currents is equal to zero; or that the two currents are 90 degrees apart in phase. In this case the line current is 71 percent of the numerical sum of the currents in the transformers. This of course is a limiting case, and will not actually occur. It is also apparent from an inspection of Fig. 1, that if the $\frac{percentage\ reactance}{percentage\ resistance}$ is the same for both transformers, the line current will be the numerical sum of the two transformer currents. This is also a limiting case, being the opposite limit to the previous one, but is a possible condition. A particular case of parallel operation, will come somewhere between these two limits. Fig. 2 shows a curve drawn between the line current expressed as a percentage of the numerical sum of the two transformer currents and the phase angle between the transformer currents. From this curve it is evident that for differences in phase angle between the transformer currents of 15 degrees or less, the line current may be assumed to be the numerical sum of the transformer currents without serious error.

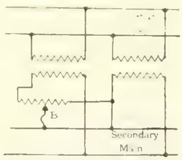


FIG. 3 BALANCE COIL

Used with two dissimilar transformers to force the desired distribution of current between them.

Example—How will the common 75 k.v.a. load be divided between a 25 K.V.A. transformer which has a copper loss of 1.5 percent and an impedance of 2.5 percent, and a 50 K.V.A. transformer which has a copper loss of 1.1 percent and an impedance of three percent?

The reactance of the first transformer will be two percent and [illegible] the second [illegible]. The angle [illegible] β) is, from equation 7,

$$[illegible] \ldots = 0.965$$

Then from equation 5,-

$$k.v.a._1 = \frac{75}{1 + \frac{50}{25} \times \frac{2.5}{3} \times 0.965 + j\,\frac{50}{25} \times \frac{2.5}{3} \times 0.259} = 28.2$$

$$k.v.a._2 = 75 - 28.2 = 46.8$$

In this example no appreciable error would have been introduced by the assumption that the line current was the numerical sum of the transformer currents, the angle $\alpha - \beta$ being approximately 15 degrees.

To take a more extreme case, suppose it is desired to parallel a two K.V.A. transformer having a copper loss of 2.25 percent, reactance of 1.1 percent and impedance of 2.5 percent, with a 50 K.V.A. transformer having a copper loss of one percent, impedance of 3.5 percent, and reactance of 3.35 percent.

From equation 7,—

$$Cosine\ (\alpha - \beta) = \frac{2.25 \times 1 + 1.1 \times 3.35}{2.5 \times 3.5} = 0.68$$

In this case the phase relation of the two currents cannot be neglected, as the angle $\alpha - \beta$ is approximately 47 degrees.

USE OF BALANCE COILS IN PARALLELING TRANSFORMERS

It has been shown that the load current in two transformers connected in parallel so divides that the terminal voltages of the two units are equal in value and opposite in time-phase. In case this distribution of the current is not that desired, it is possible, by inserting a balance coil at *B*, in Fig. 3, to force the transformers to divide the load between them in any ratio required.

The balance coil is a single continuous winding on an iron core, having a tap at some point between its two ends. This tap is so located that when the desired current distribution is obtained, the ampere-turns on the two sides of it are equal. Since the balance coil absorbs the voltage tending to produce a circulating current, this current is reduced to a value only sufficient to magnetize the core of the coil. The ampere-turns on the two sides of the tap neutralize each other so far as any magnetizing effect on the core is concerned. It is rather difficult to predetermine the value of the voltage tending to circulate current for a particular case of parallel operation. For this reason the balance coil should be designed with a fairly low flux density in its core, so that if the voltage is greater than expected, the increased flux will not saturate the core sufficiently to require a large magnetizing current, which in this case will be the current circulating between the transformers. A balance coil may also be used in paralleling three-phase transformers, the principles involved being the same.

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

JUNE 1919

Mounting and Maintenance of Car Resistors

GENERAL ARRANGEMENT

In hanging grid resistors on motor cars whether of the small city or large interurban class, it is essential that certain details receive proper attention. It is due to lack of careful forethought regarding these particular features that a great number of avoidable troubles are encountered. Consider for instance the fallacy in mounting the grid resistance directly back of the truck and in line with the wheels, without protecting the grids from wheel wash with a suitable baffle. Yet this is one of the neglected details, both when mounting the grids and maintaining them in service.

MOUNTING POSITION AND PROTECTION

When laying out the apparatus on the car underframing, the following points should be taken into consideration in regard to the position occupied by the grid resistance.

1—Mount the frames so that the grids lie in the longitudinal plane of the car. This insures a maximum of ventilation.

2—When it is necessary to mount the grid resistance where it is exposed to the wheel wash, a splash guard similar to the one here shown should be used.

3—Where it is necessary to place the grid frames close together, due to lack of room, be sure that sufficient room is allowed between the top of the grids and the car underframing for making connections.

4—The clearance between the bottom of the grids and the top of the rail should not be less than ten inches. For low-floor cars this figure can be reduced to seven inches.

MOUNTING ARRANGEMENT

The general arrangement of the grid resistance is shown in Fig. 1. Each frame of resistance is supported from strap iron hangers by four one-half inch insulated bolts. As a general rule the manufacturer supplies only the insulation for the bolts, as the bolt itself is considered standard hardware which the operating company usually has in stock or can easily obtain. The strap to which the grid resistance is fastened is approximately three by five-eighths inch and the hangers from which these straps are suspended are three by one-half inches.

SCHEME OF INSULATION

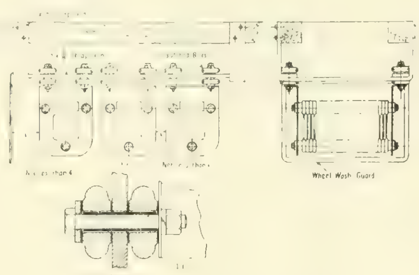
The method of insulating the grid frames for 600 volts installations is shown in Fig. 1. For 1200 volts the same arrangement is used with the addition of insulated bolts between the hangers and the straps to which the grid frames are attached.

Fig. 2 shows by cross-section the construction of the bolt. The heavy black lines indicate the insulating washers and tube, while the dotted cross-sectional pieces are the porcelain insulators.

On equipments requiring more than five grid frames, it will be necessary either to use heavier mounting straps, or more hangers. The use of three hangers is preferable to heavy straps.

FIRE UNDERWRITERS' REQUIREMENTS

To satisfy the National Board of Fire Underwriters requirements, it is necessary to observe certain regulations regarding insulation as a fire protection. When the car underframing is composed entirely, or partly, of wood over the place where the grid resistance is hung, the regulations call for a fire-proof non-metallic insulation at least one-fourth inch thick, covering a surface which extends eight inches beyond the resistance on all sides. The cable insulation must be removed for a distance of at least six inches from the terminals of the grid resistor and should be supported in a manner to give a rigid construction, to prevent vibration.



INSPECTION AND MAINTENANCE

With proper design, application, and installation, the maintenance of grid resistance should be negligible. However, even under the best of conditions certain troubles are bound to occur. Take for instance the breakage of grids. This trouble can be traced to vibration or loose stones on the road bed. When replacing broken or burned out grids, be sure that there is sufficient insulation at the proper place between the new and the old grids. It may be necessary, in a number of cases, to renew a considerable portion of the mica insulation under the nuts of the clamping bolts.

At the time of heavy inspection, and when installing new grid frames, the clamping bolts should be tightened to take up any shrinkage which may have occurred. The terminals should be checked to see that the cable connections are satisfactory. All leads should be carried up close to the car floor until it is necessary to bend down for the terminals. This prevents the cables from resting on the top of the grids.

H. R. Meyer

THE JOURNAL QUESTION BOX

OUR subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. The topics should be of general interest, information involving the specific design of individual pieces of apparatus is not supplied. Care should be used to include all data necessary for an intelligent answer.

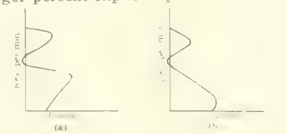
A PERSONAL reply is mailed to each questioner enclosing a stamped, self addressed envelope as soon as the necessary information can be obtained. Anonymous questions cannot be considered. As each question is answered by an expert on the subject involved, and checked by at least two others, a reasonable length of time should be allowed before expecting an answer.

1749—INDUCTION MOTOR WINDING—Your induction motor data, as published in the various issues of the Journal, has been most helpful and is of great assistance to those whose duties bring them in contact with the operation of induction motors. I would greatly appreciate, if you will inform me as to the calculations for figuring a new winding, in making a change from two to three phase, and from three to two phase. How would the difference compare in number of turns, throw and size of wire? J.W.T.

This and other similar questions are answered completely in an article on "Reconnecting Induction Motors" by Mr. A. M. Dudley in the Journal for February 1916, page 459, which is now available in reprint form, at 50 cents per copy. C.R.R.

1750—SYNCHRONOUS MOTOR TROUBLE—We have a synchronous motor which drives a direct-current generator, so that its starting duty is a minimum. We have had trouble starting for a year. Finally the stator coils and one coil in the "starter" or compensator were burned out. It has been overhauled and seems in good condition. When started from the alternating-current side it reaches a speed of 300-400 r.p.m. and refuses to increase even with the full voltage applied. Normal speed 900 r.p.m. Normal voltage 2200. Direct-coupled exciter. All phases show approximately 1500 volts in the starting position and 2200 volts in the running position. The stator winding is of the concentric type one coil per slot, *Y* connected, 8 poles. Excitation is 125 volts. Field poles are laminated with a brass collar that retains the field coils. It is too light for a damper. Fields have no squirrel-cage winding. The sub-synchronous speed has not been taken yet and I doubt if it is one half the synchronous speed i.e. 450 r.p.m. When started from the direct-current side everything seems normal, the field current is quite the same as heretofore. Exciting current may be varied from lag to leading with the exciter volts varied from 15 to 108. As we cannot bring the motor to speed on the starter, we start from the direct-current end, giving it a speed slightly above the low speed referred to, then disconnect the direct-current and put it on the starter in the usual way. The field is applied when in starting position, however, it is not unsatisfactory to wait until the starter is in the running position before applying the field. Have tried starting with the field open and shorted but unless given a boost from the direct-current side, it fails to come to speed. I dislike to [illegible] radical change such as a squirrel-cage winding or rewinding of field coils as the set [illegible] in perfect order after being placed on the line. It carries at times a 50 percent overload and keeps in step. The field current is not excessive, judging from rheostat settings and instrument readings taken before the motor was faulty. D.C.MCK. (WYO.)

Since the above motor has laminated field poles, the torque under starting conditions must be produced to a large extent by a single-phase secondary winding consisting of the brass field-coil retaining collars, either acting alone or in parallel with the field winding, in case it is short-circuited. This explains the failure of the motor to pull past the half-synchronous speed position, for a polyphase induction motor with a single-phase secondary has a stable running speed slightly below the half-synchronous speed as is shown by the speed torque curve in Fig. (a). For a simple analytical determination of this curve, refer to an article entitled "Polyphase Induction Motor with Single-phase Secondary" by Mr. B. G. Lamme in the JOURNAL for Sept. 1915, p. 394. The stability of the motor at a speed so far below the half-synchronous speed is probably due to the high resistance of the single-phase secondary path. The effect of a high-resistance secondary winding is to change the shape of the speed-torque characteristic, so that a larger percent slip is required to furnish



FIGS. 1750(a) and (b)

a given torque, as is illustrated in Fig. (b). If the counter torque is reduced to a minimum by raising the brushes on the direct-current machines and opening their field circuits, there is a slight chance that the torque produced by the laminations of the poles, which act as a very imperfect polyphase damper winding, would be sufficient to overcome the negative torque, due to the single-phase winding, and carry the rotor past the half synchronous speed position. However, if this method fails to bring the motor up to synchronous speed, the only alternative is to provide a more effective polyphase damper winding. In the present case, this might be accomplished by putting brass or copper wedges between the pole faces and allowing them to project under the pole face as far as practicable. However the manufacturers of the machine should be consulted before any radical charges are made. C.M.L.

1751—20 HP ROTOR IN A 37 HP STATOR—What service can be expected from a motor comprised of a 37 hp, 1200 r.p.m. stator and a 20 hp, 900 r.p.m. squirrel-cage rotor? Their parts are interchangeable mechanically. J.H.B. (WYO.)

In an eight-pole motor, the end ring is in effect in eight parallels; while in a six-pole motor the end ring is in six parallels, which causes the same end ring to have 80 percent more resistance when used with a six-pole primary than when used with an eight-pole primary. The resistance of the bars is not effected by the different primaries and since in a six or eight-pole motor the bar resistance is a large part of the total resistance, the large increase in the ring resistance does not make a corresponding increase in the total resistance. This increase in the secondary resistance will give an increased rotor loss and rotor heating but not sufficient to injure the motor. This increase in resistance will also give greater slips, greater starting torque and slightly lower efficiency. The above is on the assumption that the 900 r.p.m., eight-pole rotor is not a special, high-slip rotor but a rotor for normal slip, in which case it should be possible to obtain the full rating from the 37 hp primary with this squirrel-cage rotor. B.B.R.

1752—VENTILATION OF ALTERNATOR—Assume the case of a 5000 k.v.a., 2300 volt alternator having both intake and discharge air ducts. What rise in temperature of the cooling air may we expect, the required volume of air being furnished the machine at full load? What would be a fair value to assume for the pressure drop through a cheese cloth screen placed in the intake duct? Would it not be more correct in approximating the cooling air required to take it as cubic feet per minute per ampere rather than per kilowatt? M.J.I. (D.C.)

A temperature rise of 25 to 30 degrees C. may be expected in the cooling air of a turbogenerator. The pressure drop through a cheese cloth screen is a variable quantity, depending on the fineness of the mesh and the amount of dirt suspended in the screen. Tests at a velocity of 50 ft. per minute have shown that drops are obtained of 0.2 inches of water column when the screen is clean, and 1.5 inches when dirty. The quantity of cooling air cannot be based on ampere rating, as the copper loss in a turbogenerator is small, compared with the iron loss and friction and windage, which are practically constant for all loads. For this reason, the cubic feet of air should be based on the total loss in the generator. A safe figure to allow is approximately 80 cubic feet per kw loss. A turbogenerator maximum rated at 5000 k.v.a., will require approximately 24 000 cubic feet of air per minute. S.L.H.

1753—TRANSFORMER RELATIONS—(a) I have three 2400 volt to 120 volt single-phase transformers connected delta to star as in Fig. (a) the polarities of these transformers are as shown in Fig. (c). Now with the phases as indicated by *A*, *B* and *C* on

the primary side of the transformers, as in Figs. (a) and (b), I would like to know if I have the secondary leads marked right, for their proper phases, in reference to the primary or incoming lines. (b) At any instant that the current is flowing into the primary side of the transformers in Figs. (a) and (b), is the current in the secondary leads flowing into or out of the transformers? (c) I can see the action of a current transformer as compared to that of a potential transformer, the only thing that is not quite clear to me is the primary voltage or drop across the primary coil of current transformer. Is this primary voltage in phase with the primary current of current transformer, regardless of whether this current is in phase or not, with the main line or generator voltage? (d) In a vector diagram of a single-phase transformer, as in Fig. (d) and as shown in a great many books, there is an angle shown between the impressed-electromotive force E_1 and the counter electromotive force *ED*. Does this angle actually exist, or is it just drawn this way to show the difference between the two voltages due to reactance and resistance drop?

G.S.P. (ILL.)

(a) The application of letters to transformer leads is a purely arbitrary matter. The A.I.E.E. has formulated

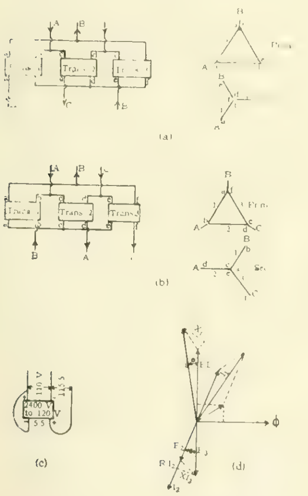


FIG. 1753 (a) to (d)

a set of rules covering the lettering of the leads for single-phase transformers and for three-phase transformers, but the lettering of the leads of single-phase transformers is not changed when they are connected in a bank. The diagrams given in Figs. (a) and (b) show that, with the connections shown, if the primary delta rotation is in the order *a-b-c*, the secondary star rotation in the order *a-b-c* is in the same direction—which is correct. (b) At any instant the current in the primary winding of a transformer must be flowing around the core in a direction opposite to the current in the secondary winding. With a transformer of the polarity shown in Fig. (c), this means that at the instant when current is flowing into the left-hand primary lead, it is flowing out of the right-hand secondary lead. (c) Think of any electrical device connected in series with a line carrying current. If the device has resistance but no reactance, the voltage drop across its terminals will be in phase with the current flowing through it, that is with the current in the line. If the device has reactance without resistance, the voltage drop across its terminals will be at an angle of 90 degrees with the current in the line and in a device having both resistance and reactance the voltage drop across the terminals will be somewhere between zero and 90 degrees from the current in the line. A series transformer carrying load may be regarded as such a device. The relation of the voltage and current in the secondary of the series transformer will be determined by the characteristics of the instrument connected to it. The series transformer itself also has resistance and reactance which will add something to the resistance and reactance of its load. Therefore, the drop across its primary will be at an angle with the current in the line depending upon the relation of resistance to reactance. (d) In drawing vector diagrams of transformers, it is usual to consider the whole resistance of the transformer as one quantity and the whole reactance as one quantity. In reality though, part of the resistance is in the primary winding and part is in the secondary winding, while part of the reactance is in the primary winding, part in the secondary winding and part in the leakage between primary and secondary. A certain amount of the applied voltage must therefore be used up in circulating current against the resistance and reactance of the primary winding and the induced voltage in the primary is consequently slightly smaller than, and slightly out of phase with the applied voltage.

J.B.G.

1754—UNDERCUTTING MICA—Where could I get a good hand tool for undercutting the mica on a commutator? I have been using hack saw blades but this is very slow. Sometime ago I saw a description of some small hand tool which was very successful but have forgotten where.

S.E.G. (CAL.)

The only power undercutting tool of which we know is the motor-driven tool. The air-driven undercutting tool is not regarded with favor by us as satisfactory results have not been obtained by its use. There is now on the market a portable motor-driven rig (about the size of an electric drill) which uses a worm drive but as the saw is at least 1.5 inches in diameter, this rig does not readily adapt itself to small commutators. For the undercutting of small commutators by hand, the ordinary hack-saw method is hard to beat, although quick and satisfactory results can be obtained with a riffle file, if used until the corners of the bars are slightly bevelled off, so as to be sure the mica is all below the copper. After using either a hand hack-saw or power saw, the corners of the commutator bars should always be taken off with a file or scraper. A number of methods of undercutting are illustrated in an article "Care and Operation of Commutators" by Mr. W. A. Dick in the JOURNAL for May 1912, p. 378; also in Railway Operating Data, for Nov. 1916, p. 555.

M.D.

1755 SWITCHING LOADED TRANSFORMERS—We have in a substation transformers for light and power. They are Scott connected, high tension side 11 000 volts, three-phase; low tension 2400 volts, two-phase, 4 wires; capacity 500, 1000 and 3000 kw. Which side of the transformers should be closed first when putting them into service? When taking off which side should be disconnected first? We found by closing our 11 000 volt oil switch first we never seem to make a surge on the bus. We then tried closing the 2400 volt oil switch first, and got very bad operating conditions. Every time we would close this oil switch the charging current was very heavy, making a surge in the voltage on the bus. We ran mercury arcs and by closing this switch, we would throw three or four arcs off the line.

H.M. (N.J.)

When connecting a transformer to the line there is generally a surge of magnetizing current. The magnitude of the surge depends upon the position of the voltage cycle at which the circuit is closed. This current is at a low power-factor and, if drawn through considerable reactance, the voltage drops momentarily. There is generally little or no preference in switching on 11 000 or 2400 volts. In the above instance the difference must be due to the relative reactance of the two circuits. When switching on the 11 000 volt side, the reactance of the incoming 11 000 volt line only is involved, while when switching on the 2400 volt side the surge of current must pass through the reactance of the transformers in that substation as well as that of the 11 000 volt line. There should be no difference in the performance of the transformers for the different order of disconnecting, as disconnecting transformers of this voltage does not produce surges of current.

J.F.P.

1756—PULL-OUT TORQUE OF SYNCHRONOUS MOTOR—We have installed in our substation a 1000 kw motor-generator set. About how many amperes will the motor field take before it will pull out when over-excited, also at about what current will it pull out when under-excited?

H.M. (N.J.)

The ability of a synchronous motor to carry load is increased as the field is over-excited. When the field excitation is decreased, the pull-out point is lowered. The actual value of current which will give a certain pull-out torque depends upon the design of the particular machine in question. See articles on "Performance Curves of Synchronous Machines" by Q. Graham, in the JOURNAL for January 1917, p. 21; also "Synchronous Motor Operation" by Ralph Kelly, August 1917, p. 313.

Q.G.

1757—GROUNDING OF SQUIRREL-CAGE WINDING—Why is it a squirrel-cage rotor winding can be and is, grounded to the spider or laminations with no disastrous results? Why are the copper bars separated from the laminations by paper cells in the slots, if not for insulation?

J.F. (N.Y.)

The secondary voltage of a squirrel-cage motor is low, being proportional

to the percent slip times the transformer ratio of primary and secondary voltages. It is so low that there will be very little current flowing any where except through the bars and end rings, these having a low resistance compared to the paths through the iron. Formerly it was thought necessary to have the bars insulated to prevent any current taking paths through the iron and all bars were insulated. This has been proved unnecessary and the elimination of the insulation makes a better mechanical construction than before.

T.P.K.

1758—POLARITY OF GENERATOR—Can the polarity of a compound, commutating-pole generator be changed any other way than by changing the residual magnetism? Why can't the polarity be changed by interchanging the two leads at the collector rings?

J.G.M. (N.J.)

If a source of separate excitation is available, perhaps the simplest way to reverse the polarity of a direct-current generator is to reverse the residual magnetism. The polarity at the machine terminal board can be reversed by interchanging the leads of each of the windings,—armature, series, commutating pole, and shunt field. The residual magnetism is not changed in this case. The polarity at the switchboard may be reversed by interchanging the main leads of the generator and the shunt field leads. If the machine is separately excited, the polarity may be reversed by reversing the leads of the armature, the series winding, and the commutating pole winding.

F.L.M.

1759—FUSING OF COPPER WIRE—I would appreciate very much some information upon the fusing current for copper wire. I wish to know if you can furnish me any data or information upon a method of arriving at the amount of current in amperes which will fuse No. 1/0 copper wire and 4/0 copper wire in one-fifth, one-third, one-half and one second respectively.

W.T.B. (MD.)

In estimating the current required to fuse a wire in a short period of time, the heat dissipation due to convection and radiation may be neglected. The energy required to raise the wire to the melting point then becomes a function solely of the thermal capacity of the wire. With this assumption the time required for a given current to raise a wire to its fusing temperature may be approximately determined from the following formula:

$$t = \frac{0.262\,\pi\, d^4\, s\, w}{I^2\, r_0\, a}\ \log_e \frac{1 + a\,T_m}{1 + a\,T_r}$$

Where,

t = time in seconds.
d = diameter of wire in cm.
s = specific heat of wire in calories per gram per degrees C.
w = density of wire in grams per cc.
I = current in amperes.
r_0 = resistivity of wire at 0°C. in ohms per cm³.
a = temperature coefficient of resistance of wire.
T_m = melting point of wire in degrees C.
T_r = initial temperature.

Substituting the following values for copper,

s = 0.11 (approximate mean value between initial temperature and melting point.)
w = 8.9
r_0 = 1.6×10^{-6}
a = 0.005 (mean value between initial temperature and melting point.)
T_m = 1083
T_r = 20

We have

$$t = 5.4 \times 10^8\ \frac{d^4}{I^2}$$

or

$$I = 23000\ \frac{d^2}{\sqrt{t}}$$

The following table gives the results desired as obtained from the above formula. The writer has no experimental data available to check these figures.

Size of Wire	Time in Seconds	Current in Amperes
4/0	1/5	35 000
	1/3	27 000
	1/2	22 000
	1	16 000
1/0	1/5	70 000
	1/3	55 000
	1/2	45 000
	1	32 000

The above values give the current which will raise the wire to the fusing temperature in the specified time. An additional time will be required to fuse the wire and interrupt the circuit. This additional time is indeterminate.

C.T.A.

1760—CHANGING DIRECT-CURRENT MOTOR TO GENERATOR—I have a four-pole 500 volt 1600 r.p.m. direct current motor which I wish to change to a direct-current, 125 volt generator. This motor has 47 slots, 93 bars, two brush holders, one quarter inch thick brushes, wave wound, six turns of two No. 16, D.C.C. wires per coil. Would placing four brush holders instead of two reduce the armature heating, when wave wound? Would it allow more current to be drawn from the armature and would it reduce the voltage and increase the current. The above motor has not the capacity marked on name plate, only the make, voltage and speed.

S.E.G. (CAL.)

If this motor were to run as a generator at 1600 r.p.m. it would be necessary to put a high resistance in the shunt field to reduce the shunt field current enough to lower the voltage to 125 volts. A very small shunt field current would probably result in the voltage being unsteady. To avoid this the motor should be run as a generator at about 500 or 550 r.p.m. At this speed it will be necessary to connect all of the shunt coils in parallel to get the field current to give the voltage desired. In any case the brushes would have to be shifted to get best commutation. If this is a compound-wound motor it probably will be necessary to make the speed above 550 r.p.m. and to shunt out part of the current from the series coil. The motor, when changed as given, would carry about the same amperes load as when run as a motor. Since the output is proportional to the volts times the amperes, and in this case the amperes are constant while the volts are 125 now as compared with 500 as a motor, the machine as a generator will give only about one quarter as much output as when a motor. Putting on four brushes instead of two, under the conditions as above, will not reduce armature heating. It will not appreciably change the voltage or increase the current. It will probably improve commutation a little. If it is desired to get the same generator output as was gotten as a motor the armature will have to be rewound so as to carry four times as large a current as before, and will have to run again at about 1700 r.p.m. In this case then for the sake of commutation all the brushes possible should be put on. Four brushes would carry twice the current of two, with the same kind of commutation. To carry four times as much current with the same commutation you would need eight brushes. It is very unlikely that that many can be put on.

M.S.H.

1761—PARALLEL OPERATION OF EXCITERS—Assume in a power station four 125 volt compound-wound exciters, that among these four exciters there are three different makes, speeds and kinds of drive, and that only one of the three types has commutating poles, and also that they all can be successfully paralleled at 75 to 135 volts. Under the above assumption, supposing exciter *A* is exciting one alternator at no load and is up to only 43 volts, is it reasonable to expect one of the dissimilar exciters *B* to be successfully paralleled at 43 volts with exciter *A*, pick up the load and allow exciter *A* to be switched off without causing any trouble on the exciters or the alternator? The above condition exists in our plant and during a test an attempt to parallel at any voltage less than 70 resulted in one exciter taking the load away from the other and the condition became worse as the voltage at which they were paralleled was lowered.

C.T.M. (MAINE.)

The series field circuits of direct-current generators that are to operate in parallel ordinarily are adjusted so that the series fields take currents proportional to the loads on the machines, and the compounding curves are approximately alike. At voltages other than normal the compounding curves change, and are likely to become dissimilar, especially if the machines are of different types. Thus two generators may be adjusted for flat compounding at or near rated voltage, and yet at half voltage they may over-compound considerably, mainly on account of the series field becoming relatively stronger; and unless they are duplicates, the amount of overcompounding will probably be different. As a result, they would not share the load properly at the low voltage. In view of the care sometimes required in paralleling unlike machines at normal voltage, it would seem that satisfactory parallel operation over a range of 75 to 135 volts, obtained with the exciters in question, would be all that one could expect. In general, it seems that the necessity of switching exciters at voltages much less than two-thirds of normal, is open to question.

F.L.M.

1762—TESTING WATTHOUR METERS—I have been testing some Westinghouse type *C* polyphase watthour meters and find almost all of the style *E* from 100 to 300 amperes self-contained meters having a full load speed of 50 r.p.m. running fast. I use a Westinghouse polyphase rotating standard to check with and if the method outlined below is not correct will you tell me where I make my mistake and if O.K. can you give me any good reason for these meters running fast. I use this same method on all other meters and they check all right. The standard has just been checked and found correct. Meter to check:—Westinghouse polyphase type C 300 amperes, 400 volts, style E, full load speed, 50 r.p.m. self contained meter. The watthour constant is 80. The rotating standard is set for 5 amperes, 100 volts. The watthour constant is 0.666. Used with the rotating standard are current transformers 333.33 to 5 amperes and potential transformers 400 to 100 volts thus making the watthour constant for the rotating standard 177.598 and found as follows: C.T. 333.333 to 5 or 66.666 to 1 P.T. 400 to 100 or 4 to 1. 66.666 x 4= 266.664 x 0.666 (Standard constant for 5 amperes 100 volts) = 177.598. Taking 20 revolutions of the type of C meter the rotating standard should make 9 revolutions. Is this correct?

E.H.D. (CONN.)

The watthour constant of the rotating standard is 177.77 when used with 333.33 to 5 current transformers and 400 to 100 voltage transformers. The standard should therefore make nine revolutions while the type C meter makes twenty revolutions. However, the transformer errors may be large enough to cause the portable to rotate less than nine revolutions when the type C rotates twenty revolutions thus causing the type C meter to appear to be running fast. The portable standard should be checked with the transformers to determine the watthour constant.

A.T.R.

1763—TESTING INDUCTION MOTORS—In the Journal for March, 1917 there is an article by Luther H. James. "Calculating the Performance of Polyphase Induction Motors". On page 120 in the tabulated part under the heading of Text values and Motor constants about half way down it reads $r_1 = (reading)$ x

$\frac{1.135}{2} = 1.3$. On page 119 at bottom giving no load amperes, etc., it says *Measured primary resistance* $r_1' = 1.3$. I presume that r_1' here should read r_1 since four lines down $r_1' =$ *Modified primary resistance.* Will you please explain $r_1 = (reading)$ x $\frac{1.135}{2} = 1.3$.

What is the $\frac{1.135}{2}$ and where and how found? Would this method of finding R_t and X_t be suitable for use in calculating the motor performance by the Steinmetz method. I think such articles would be greatly enhanced if the table of test values and resistances, etc., were given, also if the type of circle diagram were named. Did the author use the Heyland diagram as described by Karapetoff, or Specht, or Arnold, or some other?

L.P.R. (CAN.)

By the term "reading in the equation $r_1 = (reading)$ x $1.135/2 = 1.3$, is meant the ohms resistance between any two primary leads at 25 degrees C. It was determined by test on this particular motor that the full load temperature rise above air, was 34 degrees C. From the law of increase in resistance with rise in temperature, there is an increase of one percent in resistance for every 2.5 degrees rise in temperature, or 13.5 percent increase with a temperature rise of 34 degrees. It is stated in the article that equivalent single-phase values are used throughout the calculation. To obtain the single-phase resistance of the primary winding, the resistance between any two leads must be divided by 2, thus is obtained the constant 1.135/2. In the tabulation $r_1' = 1.3$, r_1' is a typographical error. This should be $r_1 = 1.3$. We have used the term "Measured primary resistance" here in order to distinguish it from the term "Modified primary resistance" used later in the calculation. Specht's diagram was used in obtaining comparative data on this motor. It would not do to use the modified values of secondary resistance, total resistance, and reactance in the Steinmetz method of calculation, for in this method the performance of both the primary and secondary of the motor are obtained simultaneously; whereas in the method under discussion, the performance of the secondary of the motor is segregated completely from that of the primary. After the current and watts taken by the secondary are determined for any desired output, these values are added, in their proper phase relation, to the current and watts taken by the primary, which values are considered constant at all loads. In using the Steinmetz method of calculation, the writer has invariably obtained lower values of slip and higher values of efficiency than obtained by test or by any other method of calculation, and on this particular motor there is no exception. The Steinmetz method with "unmodified" constants" gave the following results:—Efficiency at full load 73.3 percent. Maximum Torque 33.5 lbs. Power-Factor at full load 45.3 percent. Slip at full load 6 percent.

L.H.J.

1764—ROTARY CONVERTER PARTLY LOADED—Will you please give an approximate idea of the saving in running a 500 kw, 3 phase Westinghouse rotary converter with the transformers and a 160 kw with its transformers, same make. The 500 kw is loaded to only 125 kw and this same load to be placed on the 160 kw. Also the core loss of one 300 k.v.a. lighting 4600-220-110 volt single-phase transformer at full load and at 10 percent load. Also the core loss at full load of one single-phase 40 kw transformer of the same kind.

J.E.MCH. (MICH.)

Assuming 250 volts, 60 cycles, 3 phase, the 500 kw converter has six kilowatts more loss at a load of 125 kw than the 160 kw machine with the same load. The three transformers for the 500 kw converter will have 475 watts more loss at 125 kw load than the three transformers for the 160 kw rotary. A 300 k.v.a., 4600 to 220-110 volt, 60 cycle transformer has 2700 watts core loss, regardless of the load and a 40 k.v.a. transformer has 240 watts core loss.

C.R.C. & J.B.G.

1765—ELECTROLYSIS—A coal dock has three parallel tracks on which operate the coal bridges. The dock is on filled ground and contains material that is permanently wet so that the water level is generally within two feet of the surface. The main trolley feeder to the bridges runs parallel with the outside track and the rotary converter substation is opposite this, so that it is necessary to run a feeder underneath these tracks from the substation to the trolley wire. Conditions are such that an overhead feeder cannot be used and it must be an underground cable. The rails will be bonded and tied together by means of a grounded feeder of sufficient capacity which will run directely from the rails to the negative bus in the station. The positive feeder will consist of two feeders of 500 000 circ. mil lead cable rubber covered. Over the lead will be jute and asphalt and over this will be a double steel tape which will also be protected with jute and asphalt covering. The cable will be parallel to the grounded feeder and operate at 600 volts, the load being very intermittent, consisting of heavy demands for short intervals. It is proposed to lay this cable about two feet below the surface and the question has come up as to the danger to be expected from electrolysis. The steel tape will not be in actual contact with the lead and it has been suggested that trouble might be eliminated by having the armor grounded to the negative bus. Should any such provision be made, what are the possibilities of danger of the cable being damaged by electrolysis?

W.M.H. (ILL.)

The question gives the impression that there is only a short run of cable, crossing under the tracks. The current which it will carry in the sheath will depend upon the voltage drop in the rail bonding between outside tracks which should be very small. As the cable sheath has a protective coating it is doubtful if serious electrolysis occurs without any further precautions. But after the installation is complete voltage measurement should be made between the cable sheath and the rails. If the rails are positive to the sheath nothing need be done. If negative the rails may be bonded to the sheath or a feeder run from the negative bus to the sheath in order to eliminate the potential or reverse its direction.

A.W.C.

1766—STARTING INDUCTION MOTOR WITH SECONDARY OPEN—Recently the firm I am with sold a 40 hp, 60 cycle, 2300 volt, 720 r.p.m. phase wound rotor induction motor to a coal mining company. This motor has been used for constant speed service lightly loaded for the last few years and when we bought it was operating. The motor was started by closing a 2300 volt oil switch on the stator and then a non-reversing drum type controller was used to cut out external resistance in the rotor circuit. The people who bought this motor from us wanted a reversing controller as they wanted to use it on a hoist. As we were unable to supply this controller they bought a new 2300 volt reversing controller from another company. The

diagram showed the rotor circuit completely open when the controller is on the off position. The customer wired up the motor and controller as shown on the diagram. The controller is so built that when the handle is on the first notch none of the secondary fingers are touching the cylinder nor are they within one-fourth inch of doing so. This leaves the secondary completely open when the controller is on the first notch and the primary or stator is excited with 2300 volts. After the customer wired the motor up this way he moved the controller to the first notch and as the motor did not start he threw it off and then on again. He repeated this operation several times and then the motor winding flashed. The writer was then called on and I found that two primary coils located about 90 degrees apart around the motor were melted in two. A piece about two inches long was melted out of each coil and the arc had apparently grounded, as the iron nearest the coil was discolored but not beaded nor burnt. I claim that it is not the standard practice but the exception to wire motors up as this was done and that there is danger in opening and closing the primary when the secondary is open and that this caused the above described blowout in the primary winding of this motor. The windings in this motor are virtually as good as when they left the factory. They have never been rewound and have not been baked nor has the motor been handled roughly. The insulation is flexible and appears in the best of condition. Please advise if I am right. C.M.L. (UTAH)

In general, it is not good practice to open the primary circuit of an induction motor with all phases of the secondary open, since under certain conditions there is a considerable rise of voltage across the motor terminals, which may be several times the voltage on the line. This action is somewhat similar to the rise of voltage across the field windings of a direct-current machine when the field is broken. It is therefore seen that the switching of the primary of an induction motor with all phases of the secondary open, should be done only after carefully considering the specific application. It is quite common practice to start induction motors with one phase open circuited. Under this condition, there is no sudden rise of voltage when the primary is disconnected because the discharge of energy in the motor field is accomplished through the closed secondary phase. G.W.H.

1767—Insulation for Terminal Conductors of Generators—Please give a specification for the insulation which should be put on the connectors in splicing to the terminal conductors of large sized 2200 volt and 6600 volt alternators. M.J.I. (D.C.)

Assuming that the connector which connects the cable terminals with the switchboard cable is made of copper or brass tubing and the joints soldered, the insulation should consist of four layers of varnished insulated cloth, half overlapped. Each layer of the cloth, after it is applied, should be brushed with an insulating varnish. The outside covering or protection should be one layer of selvedge edge cotton tape. This tape should be well treated with several coats of shellac or insulating varnish. J.J.G.

1768—Rewinding Induction Motor—We have a 150 hp, three-phase, 60 cycle, 440 volt, 600 r.p.m. motor which we intend to rewind 200 hp, 2300 volt, 1200 r.p.m.. Can we do this without making any change in the rotor? The rotor is wave wound, two-circuit star and the coils have a 12 pole throw. Can we reconnect the rotor for six poles and leave the throw of the coils as they are now, or is there any other way of changing it without rewinding the rotor? A.R. (OHIO)

(a) The rotor must be changed to a six pole rotor. (b) There is no way of reconnecting a twelve pole wave winding for a six pole winding. Therefore the rotor must be rewound for six-pole operation. T.P.K.

1769—Size of Turbine Exhaust Pipe—The exhaust from a 250 k.v.a., 150 lb. steam turbine is 14 inches reduced to eight inches for connection to a small jet condenser. In event of a condenser breakdown will this eight inch exhaust be of sufficient capacity to carry off the total flow of steam with the condenser cut out, or will the exhaust line have to be fourteen inches? The full load economy of this unit operating condensing is 24.5 lbs. of steam per kw-hr. What will be the steam consumption operating non-condensing? E.W.D.C. (CAN.)

The vacuum under which the turbine is operating is not given, nor is the maximum non-condensing capacity obtainable given. Assuming 200 kw load at 23.5 lbs. per kw-hr. and 27 inches vacuum, the velocity in an eight inch exhaust pipe would be $(4900 \times 220 \times 144) \div (3600 \times 5025) = 859$ feet per second which is rather high. For non-condensing operation, assuming 200 kw capacity at 50 lbs. per kw-hr., the velocity in the exhaust will equal $(10\,000 \times 25 \times 144) \div (3600 \times 5025) = 199$ feet per second, which is about normal. For the same quantity of steam the exhaust pipe for a small size unit should be roughly six times as large in area on a condensing machine as on a non-condensing, and for units of the same capacity the exhaust on the condensing machine should be three times as large in area; these ratios being based on normal exhaust velocities of 200 feet per second for non-condensing machines, and 300 feet per second for condensing machines. J.F.J.

1770—Parallel Operation of Generators—To supply light and power for a certain city there is available a waterfall of 1796 feet static head, with plenty of water to run two 625 k.v.a. generators. In view of the enormous cost of the pipe if a single pipe line is installed, it is planned to divide the fall in two parts and have one generating station built up at the middle of the fall and the other one at the bottom. This would give a distance of approximately 2614 feet between the two generators which are to operate in parallel, and in order to eliminate the services of an attendant in the upper station after the machines are synchronized, it is proposed to use a synchronous motor-generator set as a load balancer between the two generators. What then would be the capacity of the motor generator set, the generators being two 625 k.v.a., three-phase, 60 cycle, 2400 volt, 900 r.p.m. machines? Would it be necessary to have a resistance in the generator circuit to avoid oscillation, and if so what percentage of the generator reactance would it have to be? Will you kindly give your opinion as to the advisability of this proposition. M.C. (N.Y.)

We do not understand what can be gained by the interposition of a motor-generator set. The division of true power is only dependent upon the governors of the waterwheels, head of water, etc., and the division of wattless current upon the excitation of the generators, as is well known. The motor generator set is a flexible link, but parallel operation should be satisfactory without it, especially if damper windings are added. C.J.F.

1771—Induction Motor Windings—I have a 10 hp, three-phase, 60 cycle, 440 volt, 12 pole, 108 slots horizontal motor. I would like to change this motor to 6 poles, but on account of the throw of coils (1 and 8) I can't see how it can be done using the same throw and same coils. C.E.M. (ARIZ.)

This motor must be completely rewound to take care of the change to six poles satisfactorily. It will probably be more satisfactory to purchase the new coils directly from the manufacturer of the motor, as in this way you will avoid the possibility of having the wrong number of turns or the wrong size of wire, etc. The manufacturer should be given the complete winding data of the motor, including the style and serial number from the name plate. B.B.R.

1772—Field Discharge—To what extent is it practice to dispense with field discharge resistance on generator fields using instead lightning arrestors, and what has been the results where this arrangement has been used. I noted in the description of the Essex Power Station of N. J. on pages 30 and 32 of the Bulletin Public Service, N.E.L.A. proceedings of October 1915 the following:—

"Aluminum cell arrestors are connected across the field terminals of each generator to absorb the 'inductive kick' or rise in voltage resulting from short-circuits on the high-tension windings and disturbance in the field circuit. Others are also connected across the field of the exciters to prevent reversal of polarity. It is expected that these arresters will prove much superior to the usual discharge resistance, and simplify the equipment."

The company by which I am employed uses both field discharge breakers with resistance and also lightning arrestors connected permanently across the fields of the larger power units. H.E.T. (PA.)

The use of lightning arresters in place of standard field discharge resistors has been used only in a very few cases, and its use has apparently been of an experimental nature. Unless there is a fair proportion of resistance in the discharge circuit, the use of a condenser (arrester) will tend to prolong the oscillations, although possibly it may limit the value of the initial counter e.m.f. to a somewhat lower value than is obtained by the use of the resistance alone. Cost has much to do with the ordinary application of protection against field puncture. H.A.T.

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Finding the Size of Wire

Years ago a simple table giving the ampere-feet for a given drop was sufficient for determining the size of wire to be used in a lighting circuit. In a modern power transmission system, however, new and varied elements arise so that the problem of finding the size of wire becomes difficult and involved. The ideal line would deliver the same voltage, the same current and the same power that it receives. Actual lines have characteristics which cause one or more of these factors to be modified. The three line characteristics which cause this modification are,—

The electric circuit.
The magnetic circuit.
The electrostatic circuit.

The characteristic of the electric circuit is resistance. The resistance of the conductor causes a modification in the voltage and in the wattage. The characteristic of the magnetic circuit is inductance. A transmission line is a coil of a single turn. The inductance of a circuit causes a modification in voltage but not in current or wattage. The characteristic of the electrostatic circuit is capacitance. The conductors constitute the plates of a condenser. The capacitance causes a modification in current but not in voltage or wattage.

These general statements require proper interpretation; for instance, capacitance in alternating-current transmission, by modifying the current, also modifies the voltage and the wattage because this current flows through parts of the circuit possessing resistance and inductance. It is due to these that the voltage and wattage are modified. If resistance and inductance be negligible the capacitance modifies the current only.

Other features are leakage, due to imperfect insulation, and corona, both of which modify the current and the wattage. Line resistance and inductance are in series with the load and affect the voltage; capacitance, corona and leakage are in shunt to the load and affect the current. Briefly, this states the principal fundamental relations; in actual circuits the conditions may become involved and the interrelations intricate.

These features have a direct bearing upon the power company at one end of the line, the consumer at the other end and upon the line itself. The consumer is concerned with voltage regulation; the power company with the loss of energy in the line, and the line itself with its own integrity, i.e. it must not overheat and it must possess adequate mechanical strength. The voltage drop must be within permissible limits in order that the regulation will be commercially satisfactory. The power loss in the conductors must not be excessive and must not cause overheating. Sometimes the limiting element is the voltage drop, sometimes it is the power loss, sometimes it is the temperature rise, and sometimes it is mechanical strength.

The simplest and the earliest power transmission was by direct current; here the electric circuit alone is of importance; resistance is the dominating factor. The conductors take the toll from the passing current in two forms expressed as IR and I^2R. Both are functions of the current and the resistance.

When alternating currents came into use new elements appeared. The drop in voltage is now determined not only by resistance but by inductance also and is influenced by frequency, by power-factor and by the diameter and spacing of the conductors. The effects of the magnetic circuit are added to those of the electric circuit; the magnetic flux caused by the current, as well as the flow of current in the electric circuit enters into the problem, and adds to the difficulty in determining the size of wire. Furthermore, the effective resistance is modified in large conductors by unequal distribution of the current in the conductor itself, the so-called skin effect.

When transmission voltages become high then the third or the electrostatic circuit (negligible in its effects at lower voltages) introduces new phenomena. The electrostatic field surrounding the conductors causes charging current with its consequent effect upon both the voltage regulation and the power loss. The electrostatic field also produces corona loss. The diameter and spacing of wires, the elevation as affecting the barometric pressure, and accidental conditions of fog, and sleet and snow and roughness of the conductors become modifying factors.

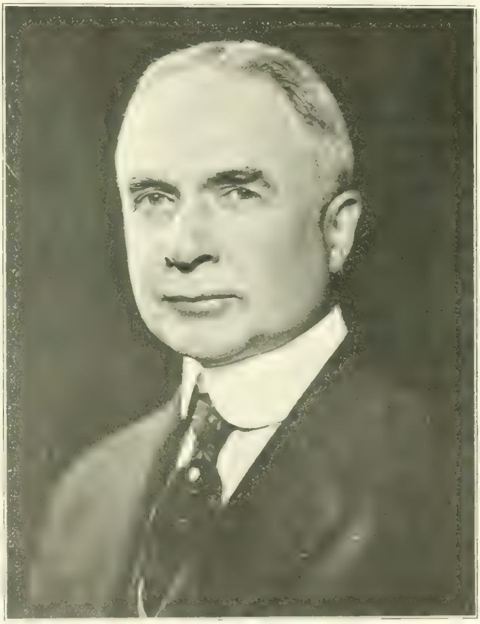
The entire problem of determining the size of wire is really a question of not exceeding permissible limits in any one of a dozen different particulars. Some feature which may be insignificant in ninety-nine cases may become the dominating one in the hundredth. The engineering data relating to these various elements have been accummulating from time to time for many years. Phenomena which were at first mysterious and the laws of which were not understood may now be expressed by definite formulæ and established constants. Mr. William Nesbit has adopted transmission line data as a sort of hobby and for quite a number of years past has been collecting this material and arranging it in convenient form. His articles beginning in this issue of the JOURNAL will prove serviceable in presenting, as a concrete whole, the general problem of the transmission line and will make accessible in convenient form the data which, until now, has not been in available form for immediate use. CHAS. F. SCOTT

Calvert Townley

President, American Institute of Electrical Engineers

Lewis Buckley Stillwell
Consulting Engineer, New York City
President, American Institute of Consulting Engineers
Past-President, American Institute of Electrical Engineers

IN THE EARLY summer of 1887, a young man in Cincinnati wrote to the Westinghouse Electric Company, at Pittsburgh, making application for a position. Mr. Pease, acting vice-president, sent him "the usual turn down letter", as he told me some years afterward, but, said Pease "he came right back at me in a way that made me think I should like to have that young fellow in my office". And so Calvert Townley, born in Cincinnati October 18, 1864, and a graduate of Sheffield Scientific School at Yale, class of '86, came to Pittsburgh as assistant to Mr. Pease. To those who know him, it is unnecessary to explain that he had not been idle during the interval between his graduation and the application to the Westinghouse Company. He had been working in an electric light station in Cincinnati and also had been doing post-graduate work which, about a year later, secured for him the M. E. degree from Yale.



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Calvert Townley

In those days H. M. Byllesby, now president of H M. Byllesby & Company, of Chicago, was vice-president of the Westinghouse Electric Company, and the selection or approval of the staff which the Company was building up was left in his hands by the president, Mr. George Westinghouse. The latter imposed but one condition, namely, that Mr. Byllesby "should appoint none but gentlemen." It was easy for young Townley to qualify as regards this requirement. On his father's side he is descended from the Townley family of England, while his mother was a Calvert, of the famous Maryland family of that name.

Those were busy and interesting days in the old shops at Garrison Alley and Duquesne Way. About two years had elapsed since Mr. Westinghouse had purchased the American patents of Gaulard and Gibbs, covering a system of distributing alternating current for lighting purposes. The lamps were connected to the secondaries of transformers whose primaries were connected in series. This system had been exhibited by its inventor at the Exposition at Turin in 1885. Starting with this William Stanley, at Great Barrington, had produced the constant potential transformer. The Lawrenceville (Pittsburgh) test in October and November 1886, had demonstrated that by using six of these transformers some 300 sixteen candle-power incandescent lamps could be supplied at a distance of more than two miles from the dynamo by current transmitted over a single-phase circuit consisting of No 4 wire.

Shallenberger was designing the first four standard transformers of the Westinghouse Company, an undertaking which he carried out with wonderful success at a time when present methods of calculating the relations of electrical and magnetic circuits were unknown. He was also designing the windings of the first standard line of Westinghouse alternators, upon the mechanical features and form of which Mr. Albert Schmidt was impressing the stamp of an ability which later brought him general recognition at home and abroad, as the foremost mechanical designer of electrical machinery in the world.

Philip Lange, in co-operation with Shallenberger, was designing and building ammeters and voltmeters, switches and the many other details needed to constitute a commercially operative lighting system. Reineman and Frank Stuart Smith were completing the lamp factory and manufacturing incandescent lamps. Charles A. Terry and his partner Franklin Pope, were filing innumerable applications for patents. Mr. Westinghouse, of course, was dominating all activities, suggesting, inventing and inspiring all with his tremendous energy and enthusiasm.

All this constituted a thoroughly congenial atmosphere for a man like Calvert Townley. While the laboratory and the shops were hard at work inventing, designing and manufacturing the new apparatus, Mr.

Pease and his young assistant under the direction of the president and vice-president, were quite as busy developing the commercial possibilities of the situation.

At that time the Edison Company was practically the only one in the United States exploiting a commercial system of incandescent electric lighting. The Thompson-Houston Company at Lynn, and the Brush Company, at Cleveland, were actively and extensively introducing the arc light, as also was Weston at Newark, but in the great field of incandescent lighting the Edison three-wire system had practically no competitor until Westinghouse challenged it with his alternating-current apparatus, and the attitude of the Edison Company toward the newcomer could not be called either friendly or receptive. It can readily be imagined, therefore, that the work of selling the new apparatus in quantities sufficient to make a satisfactory financial showing was not easy; and in all frankness it may now be admitted that to keep some of the apparatus sold after it had been shipped was hardly less difficult than to effect the original sale. But Mr. Byllesby and Mr. Pease were a strong team and young Townley promptly proved that he was an able assistant—keen, always alert, full of energy and possessing, even in those early days, an exceptional insight into human nature. He was recognized immediately as a correspondent and sales man of very unusual ability. He kept closely in touch with every new development in shop and laboratory and if there was anywhere in the commercial field, an agent of any other company who succeeded in scoring a point against the young champion of the Westinghouse Company, the incident escaped notice.

No sketch of Mr. Townley's career would be complete without some reference to the Amber Club, which was organized shortly before Christmas 1886, by the late J. Holt Gates, Fred Darlington a Yale graduate, and the writer. A few weeks in an Allegheny boarding house naturally suggested the idea of a small residence club. Darlington and I supplied the plan, and Gates provided the necessary capital. A small house on North Highland Avenue was rented and a steward and housekeeper installed. During the following winter, several new members were admitted. Townley, of course, joined the Club, and from that time its affairs progressed with accelerating velocity. By the time we numbered eight or ten, it became necessary to take a larger house and the Bailey place, at the corner of Penn Avenue and Murtland Avenue, Homewood, including a large and comfortable house and several acres of ground, was leased. The members coming from many different colleges not only thoroughly enjoyed their life together but, filled with enthusiasm and most keenly interested in the rapid development of the new system, learned much from each other by incidental conference and discussion.

From the time he joined the Club, Calvert Townley was one of its leading spirits. His interest in athletics was of the keenest and many were the competitions in tennis, quoit pitching, billiards, etc. due to his hair trigger initiative and tireless energy.

Before he married and left the Club, the roster included a number of names, since well known, in the electrical and mechanical field, among others, Charles F. Scott, Ralph D. Mershon, E. H. Wells, H. F. Du Puy, Reginald Belfield, F. S. Smith, Charles I. Young, Arthur Davis, Edward Levis, Philip and Henry Barton, Alexander Wurts, A. Saunders Morris, Arthur Hartwell, William Blunt, and O. H. Baldwin. Mr. Townley is the fourth among those early members of the Club to be elected president of the American Institute of Electrical Engineers.

Mr. Byllesby and Mr. Pease severed their connection with the Westinghouse Company in 1890, and the former was succeeded as vice-president by the late Lemuel Bannister, a man of mature years and wide business experience to whom the Westinghouse Company of the present day owes much for his able and tireless work during the difficult days of the early 90's, when the Company, carrying on a rapidly expanding business involving abnormal development costs and inadequately supplied with capital, encountered several years of severe trial.

Mr. Bannister at once recognized Calvert Townley's ability and made him his principal assistant in handling the commercial side of the business. This position Mr. Townley held for several years, earning the complete confidence, regard and admiration of his official superior and of his associates. He developed executive ability of a very high order.

As an illustration of his fertility of resource, it may be permissible now to disclose a secret of those strenuous days. Each day Townley had a session with the vice-president during which the more important questions raised by the day's correspondence were discussed and the decisions of the vice-president obtained. It happened that Mr. Bannister had a habit of watching the decreasing pile of letters, as Townley presented one matter after another and transferred those passed upon to another pile, and when about half had been disposed of, the vice-president would say "I think, Townley, we shall have to let the rest go until tomorrow." Mr. Townley immediately invented a method of surmounting the difficulty. He added to the daily pile—at the bottom, of course—a number of dummy letters, sufficient practically to double its height. The result was that thereafter, when approximately one-half of the letters which he took with him to the vice-president's office were disposed of, the entire ground had been covered so far as he was concerned. At that time Townley and I shared a large flat topped desk and I shall never forget his half boyish expression of triumph when he used to return to his seat, opposite mine, and announce "Got 'em all fixed."

Remarkable energy he always possessed and a keen insight into human nature, which was of great value to him and to the Company. With this endowment and a personality which won him friends every

where, success was assured and his career since that time has been no surprise to those who knew him then. He remained with the Westinghouse Company continuously until 1904, serving in many capacities including those of manager of the Boston office, assistant to the first vice-president and general agent. In 1904 he resigned from the Company and became acting fourth vice-president of the New York, New Haven & Hartford Railroad Company, in charge of electrification in and near New York, subsequently becoming first vice-president of the Consolidated Railroad Company (afterwards the Connecticut Company) which operated and later owned some thirty odd electric railway, power, gas and water utility corporations in New England. As vice-president of the New Haven, he was responsible for the decision of that Company to adopt the single-phase system—a decision, among the most momentous in the history of railway electrification in America.

In 1911 Mr. Townley returned to the Westinghouse Electrical & Mfg. Company—this time assuming executive duties as assistant to the president and taking charge of many unrelated activities which the Company's rapid expansion had created. As president of the Lackawanna & Wyoming Valley Railroad Company he operated and was active in the financial reorganization and sale of the property. He was vice-president of the Niagara, Lockport & Ontario Power Company until the Westinghouse interest in that utility was disposed of. He has continued to serve the company as an officer or director in many of its subsidaries, as well as to represent it on the boards of outside corporations. He toured Europe in 1913 in the interest of the Westinghouse foreign company holdings and in 1914-15 made a six months' survey of South America, skirting the entire continent. In 1917-8 with characteristic energy he pushed to a successful and prompt conclusion the construction of the Essington factories and new town of South Philadelphia in the Delaware River Valley.

In 1901 Mr. Townley became a member of the American Institute of Electrical Engineers. He has been one of the most active and useful members of the Institute, serving with exceptional ability and energy as chairman and member of many committees, and as a manager and vice-president. The scope and importance of his more recent work for the engineering profession are indicated by the following list of official positions which he either now holds or has held within the last few years:—

Chairman, Electrolysis Committee, American Electric Railway Association.

Representative of A. E. R. A. on American Committee on Electrolysis.

Chairman, Public Policy Committee, American Institute of Electrical Engineers.

Chairman, Committee on Development, American Institute of Electrical Engineers.

Member, Edison Medal Committee, American Institute of Electrical Engineers.

Member of Engineering Council (was its first secretary).

Member Pan-American Engineering Committee, American Institute of Electrical Engineers.

Chairman, Water Conservation Committee, Engineering Council.

Member, Reconstruction Committee, Engineering Council.

Member, Engineering Foundation.

Trustee and vice-president, United Engineering Society.

Member of Finance Committee, United Engineering Society.

Member, Executive Committee, Yale Engineering Association.

The following are among the papers recently presented by Mr. Townley:—

1—Paper entitled "Some Possibilities of Steam Railroad Electrification as Affecting Future Policies" presented at the 348th meeting of the A. I. E. E. Boston, March 14, 1919.

2—An address before eighteen participating Societies in the Engineers' Symposium, held in New York, March 26, 1919, entitled "The Relation of the Engineer to Legislation".

3—Hydro-Electric Development Statement submitted to the special committee of the Chamber of Commerce of the United States on "Water Power Development", January 14, 1918, on behalf of the Engineering Council.

Those who have watched his career believe that no man better qualified by ability and by long and varied experience has ever been chosen president of the American Institute of Electrical Engineers. His election to that important position comes at a highly opportune time when the Institute, like all the other great national engineering societies, is facing new conditions, which present new opportunities and demand in exceptional degree foresight, resourcefulness and sound judgment on the part of its officers. Mr. Townley resides in New York City and belongs to the Engineers, Yale, Automobile, Scarsdale, Railroad and Bankers' Clubs.

Electrical Characteristics of Transmission Circuits-I

Resistance-Inductance

WM. NESBIT

THE SERIES of articles on transmission circuits, of which this is the first, undoubtedly contains the most complete data on this subject which has ever been published. Recognizing that the majority of transmission line calculations represent relatively short distances, ordinary voltages and small amounts of power, and that they are based upon assumptions as to load, power-factor, etc., which at best are only approximate, the author has included tables and charts from which, by several different methods, reasonably accurate results can be obtained almost at a glance. Such approximate methods are very valuable for this type of work, as they allow a ready comparison of regulation, line losses, etc., at different voltages and with different sizes of wire. These approximate methods will include the well-known Mershon and Dwight charts, which are quite accurate for all but very long or high-voltage lines. They also include numerous tables entirely original with the author.

For longer transmission lines, larger amounts of power and higher voltages, more accurate methods of treatment are necessary. Exact methods of calculating such circuits are given both by the convergent series method and also by the use of hyperbolic functions. In addition, for the use of those who prefer graphical short-cut methods there is included a group of hitherto unpublished charts by Mr. T. A. Wilkinson, the results from which check very closely with the most exact mathematical solutions. Being to some extent a compilation, the series includes the latest formulas, methods and charts of such engineers as Kennelly, Dwight, Peek and others who have been more than generous in their cooperation. To illustrate the use of the various methods, 64 problems covering lines from 10 to 500 miles in length, are solved as examples, using both the short cut and the more exact methods of solution.

Because it is believed this series of articles may prove of great value to many engineers who have not had the advantages of a technical education, or who have become rusty on such subjects, the first few articles are devoted to a discussion of the fundamental principles upon which the solution of all transmission line problems are based. Throughout the whole series, it has been the author's aim to make the treatment simple and easy to understand, even at the risk of being tedious. It is, of course, not possible to include a course of mathematics in such a brief series and the mathematical solutions can only be followed by those who have had some mathematical training. For those who have not had such a training, the charts and tables should prove of immense benefit. (Ed.)

THE transmission of alternating-current power involves three separate circuits, one of which is composed of the wires forming the transmission line, while the others lie in the medium surrounding the wires. The constants of these circuits are interdependent; although any one may vary greatly from the others in magnitude.* There is first the electric circuit through the conductors. Then since all magnetic and dielectric lines of force are closed upon themselves forming complete circuits there is a magnetic and a dielectric circuit. The magnetic circuit consists of magnetic lines of force encircling the current carrying conductors and the dielectric circuit the dielectric lines of force terminating in the current carrying conductors. The close analogy of these is given in Table A, a careful study of which will help those not familiar with the subject to a clearer understanding of what happens in an alternating-current transmission circuit.

For a unidirectional constant current the magnetic field remains constant, and similarly for a unidirectional constant voltage the dielectric field is constant. With both the current and the voltage unidirectional and constant, the electric circuit alone enters into the calculations. A changing magnetic flux introduces a voltage into the electric circuit which modifies the initial or impressed voltage. This effect of the magnetic circuit, which is measured by the inductance L, storing the energy $0.5i^2L$, is a function of the current, and hence is of most importance in dealing with heavy current circuits. Similarly a changing electrostatic flux adds (vectorially) a current to the main power current. This effect of the dielectric circuit, which is measured by the capacitance, storing the energy $0.5e^2C$, is a function of the voltage, and hence is of most importance in dealing with high-voltage circuits.

In an alternating-current circuit, both the voltage and the current are continually varying in magnitude, and morever, reversing in direction for each successive half cycle. Therefore, with alternating currents, energy changes occur continuously and simultaneously in the interlinked magnetic, dielectric and electric circuits.

Figs. 1 to 5 inclusive illustrate the magnetic and dielectric field surrounding conductors carrying current. Figs. 1 and 3 represent respectively the magnetic and dielectric circuits when the conductors are far apart and Figs. 2 and 4 when they are close together. Fig. 5 represents the resultant of the superimposed magnetic and dielectric fields.

The magnetic field surrounding a conductor which is not influenced by any other field is represented by concentric circles. This field is strongest at the surface of the conductors and rapidly decreases with increasing distance from the conductor as indicated by the spacing of the lines of Figs. 1 and 2.

The dielectric stresses surrounding conductors are represented by lines drawn radially from the conductor. The strength of the dielectric field likewise decreases with the distance from the conductor as is indicated by the widening of the space between the lines. The magnetic and the dielectric lines of force always cross each other at right angles, as shown in Fig. 5.

*For a further description of these circuits see "Alternating Currents" by Prof. Carl E. Magnusson, from which Figs. 1 to 5 are reproduced with the permission of the author.

RESISTANCE OF COPPER CONDUCTORS

In Table I the resistance per thousand feet is listed and in Table II per mile of single conductor. Values are given for both solid and stranded copper conductors at both 100 and 97.3 percent conductivity and corresponding to various temperatures between zero and 75 degrees C. The foot notes with these tables cover all of the pertinent data upon which the values are based.

The resistance values in Table I corresponding to temperatures of 25 and 65 degrees C. were taken from

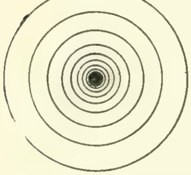


FIG 1
MAGNETIC FIELD OF SINGLE CONDUCTOR

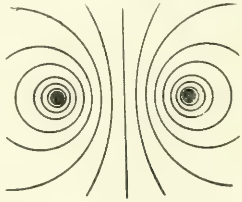


FIG 2
MAGNETIC FIELD OF CIRCUIT

THE MAGNETIC CIRCUIT

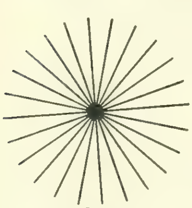


FIG 3
DIELECTRIC FIELD OF SINGLE CONDUCTOR

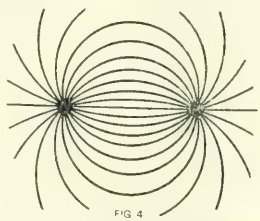


FIG 4
DIELECTRIC FIELD OF CIRCUIT

THE DIELECTRIC CIRCUIT

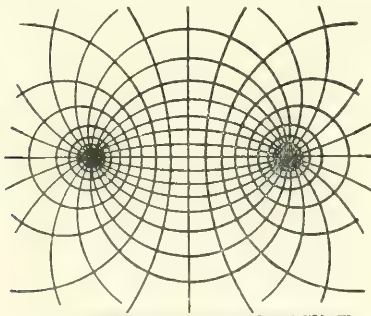


FIG 5 COMBINED DIELECTRIC AND MAGNETIC CIRCUITS
THE ELECTRIC CIRCUIT

Bulletin 31 of the Bureau of Standards issued April 1st, 1912. The resistance values (taking into account the expansion of the metal with rise in temperature) for the other temperatures were calculated in accordance with the following rule from page 10 of Bulletin No. 31.

> The change of resistivity of copper per degree C. is a constant, independent of the temperature of reference and of the sample of copper. This resistivity-temperature [illegible] for general purposes as 0.0409 ohm [illegible]

As an illustration:—A 2 000 000 circ. mil stranded copper conductor at 100 percent conductivity, has a resistance of 0.00623 ohm per 1000 feet at 65 degrees C. Required to calculate its resistance at zero degrees C.

$65 \times 0.0409 = 2.6585$ ohms (mil-foot) temperature correction or 2658.5 ohms (mil, 1000 feet). $\frac{2658.5}{2\,000\,000} = 0.00133$ ohm change in resistance. $0.00623 - 0.00133 = 0.0049$ ohm resistance at zero degrees C.

It has been customary to publish tables of resistance values based upon a temperature of 20 degrees C. and 100 percent conductivity. The operating temperatures of conductors carrying current is usually considerably higher than 20 degrees C. and therefore calculations based upon this temperature do not often represent operating conditions. Neither does copper of 100 percent conductivity represent the usual condition for transmission circuit copper, whose average conductivity is probably nearer 97.3 percent. The values in Tables I and II furnish a comparison of resistance for annealed and hard drawn copper of stranded and solid conductors at various temperatures based upon the new "Annealed Copper Standard".

SKIN EFFECT

A solid conductor may be considered as made up of separate filaments, just as a piece of wood is made up of separate fibres. As a stranded conductor is actually made up of a number of separate wires, such a conductor will be considered in the following explanation. The inductance of the various wires of the cable will be different, due to the fact that those wires near the center of the cable will be linked by more flux lines than are the wires near the outer surface. The self-induced back e.m.f. will therefore be greater in the wires located near the center of the cable. The higher reactance of the inner wires causes the current to distribute in such a manner that the current density will be less in the interior than at the surface. This crowding of the current to the surface or "skin" of the wire is known as "skin effect".

Since the self-induced e.m.f. is proportional to the frequency as well as to the total flux linked, the skin effect becomes more pronounced at higher frequencies of the impressed e.m.f. It also becomes greater the larger the cross-section, the greater the conductivity and the greater the permeability of the conductor.

As a result the effective resistance of a conductor to alternating current is greater than to direct current. The effective resistance of nonmagnetic conductors to alternating current may be obtained by increasing their direct-current resistances by the percentages in Table B, which were derived by the formulas in Pender's Handbook. Thus the ohmic resistance of a 1 000 000 circ. mil cable is approximately 8.4 percent greater at 60 cycles than its resistance to direct current at a temperature of 25°C. If the temperature of the conductor is 65°C, its 60 cycle ohmic resistance will be approximately 6.4 percent greater than its direct-current resistance. The practical result of skin effect is to reduce the carrying capacity of large cables. As indicated by the values in Table B, skin effect may be neglected when employing non-magnetic conductors ex-

cept in the use of very large diameters. It is usual to manufacture cables of very large diameter, especially for service at high frequencies, with a non-conducting core. In case of magnetic conductors, such as steel wire or cable, as is some times used for long spans or short high voltage feeders, skin effect must be carefully considered.*

TABLE A—COMPARISON OF THE THREE CIRCUITS

THE ELECTRIC CIRCUIT	THE MAGNETIC CIRCUIT	THE DIELECTRIC CIRCUIT
Current I	Magnetic Flux ϕ	Dielectric Flux ψ
Voltage $E=RI$	Magnetomotive Force $F=n\,i$	Electromotive Force $E=Q/C$
Electric Power	Magnetic Energy	Dielectric Energy
Resistivity	Reluctivity	Elastivity $1/K$
	Reluctance R	Elastance S
Resistance $R=W/I^2$	Inductance $L=\phi/i$	Capacitance $C=Q/E$
	Reactance $x=\omega L-1/\omega C$	
	Impedance $z=\sqrt{r^2+x^2}$	
Conductivity γ	Permeability $\mu=B/H$	Permittivity K
Conductance $g=W/E^2$	Permeance $M=\phi/4\pi F$	Permittance
Conductance $g=r/z^2$		(Capacitance) C
	Susceptance $b=x/z^2$	
	Admittance $y=1/z=g-jb=\sqrt{g^2+b^2}$	

INDUCTANCE

Any moving mass, for instance a flywheel in motion, will resist a change in velocity. That is, the inertia of the moving mass will tend to keep the mass moving when disconnected from the source of power. On the other hand the inertia will oppose any effort to speed up the movement of the mass.

In a similar manner, the inductance of an electric circuit resists a change in current. The cause of inductance in an electric circuit is the magnetic field which surrounds the circuit. When the current changes this magnetic field changes correspondingly, and in effect cuts the conductor, producing an e.m.f. in it. This e.m.f. of self induction has such a direction as to resist the change in current. While the current is increasing, energy is stored in the magnetic field and while the current decreases, the magnetic stored energy is returned to the electric circuit. This effect of the electric current on the surrounding space is termed magnetic induction.

Unit of Inductance—When a rate of change of current of one ampere per second produces an e.m.f. of one volt, the circuit is said to have a unit of inductance called a henry. The henry being inconveniently large, a thousandth part of it, called the millihenry, is the usual practical unit. This unit is the coefficient of self-induction and is represented by the letter L.

DISTRIBUTION OF FLUX

When current flows through a conductor, a magnetomotive force (m.m.f.) is established of a value proportional to the current. This m.m.f. is of zero value at the center of the conductor and increases as the square of the distance from the center until the surface is reached. (This statement as well as those following is based upon the assumption of a uniform distribution of current throughout the conductor, the conductor being of non-magnetic material and located in non-magnetic surroundings, such as air). At the surface it becomes maximum for a given current and remains at this maximum value for all distances beyond the surface. It is customary to think of the magnetic field surrounding conductors as concentric circles of lines of force.

A physical picture of the magnetic field density surrounding a current carrying conductor A is shown by Chart I. The magnetic density due to the return circuit (conductor B) is indicated in outline by broken lines. The horizontal divisions represent the distance from the center of conductor A and the height of the curve measured vertically the intensity of the field at the corresponding distance. The radius of the conductor has been assumed as unity, and maximum field density (always at the surface of the conductor) as 100 percent.

The intensity of the magnetic field starts at zero at the conductor center, and increases (with uniform distribution of current in the conductor) directly as the

TABLE B—INCREASE OF EFFECTIVE RESISTANCE DUE TO SKIN EFFECT.

For various sizes of solid copper rods. For stranded conductors of equivalent cross sectional area the skin effect is practically the same as for the solid conductor.

Area in Circ. Mils.	Diameter in Inches of Stranded Conductor	Diameter in Inches of Solid Rod	Percent Increase of Copper Wires Above the Direct-Current Resistance Due to Alternating-Currents of Different Frequencies — Based Upon Direct Current Resistance at 25 Degrees C. (77 Degrees F.): 15 Cycles	25 Cycles	40 Cycles	60 Cycles	133 Cycles	Based Upon Direct-Current Resistance at 65 Degrees C. (149 Degrees F.): 15 Cycles	25 Cycles	40 Cycles	60 Cycles	133 Cycles
2 000 000	1.631	1.414	2.2	6.0	14.1	28.0	78.6	1.7	4.5	10.9	22.1	67.0
1 800 000	1.548	1.342	1.8	4.9	11.7	23.7	70.4	1.3	3.7	9.0	18.5	60.0
1 600 000	1.459	1.265	1.4	3.9	9.4	19.4	61.4	1.1	3.0	7.3	15.0	51.8
1 500 000	1.412	1.225	1.3	3.4	8.4	17.4	57.3	0.9	2.6	6.4	13.5	47.4
1 200 000	1.263	1.096	0.8	2.1	5.5	11.7	42.7	0.6	1.7	4.1	9.0	34.8
1 000 000	1.152	1.000	0.6	1.5	3.8	8.4	33.8	0.4	1.1	3.0	6.4	26.2
750 000	0.998	0.866	0.3	0.9	2.2	4.9	20.6	0.2	0.7	1.7	3.7	16.4
500 000	0.815	0.707	0.1	0.4	1.0	2.2	10.1	0.1	0.3	0.7	1.7	7.7
250 000	0.575	0.500	0.0	0.1	0.3	0.6	2.7	0.0	0.1	0.2	0.4	2.0

*References—For a bibliography on the subject of skin effect see article "Experimental Researches on Skin Effect in Conductors" by A. E. Kennelly, F. A. Laws, and P. H. Pierce in *A. I. E. E. Trans.*, Vol. 34, Part II of Sept. 1915. This article ends with a bibliography on the subject embracing a very complete list of articles.

"Calculation of Skin Effect in Strap Conductors" by H. B. Dwight in *Electrical World*, March 11, 1916.

"Skin Effect in Tubular and Flat Conductors" by H. B. Dwight in *A. I. E. E. Trans.* for 1918.

distance from its center until its surface is reached, where it becomes maximum. For distances beyond the surface of the conductor, the field intensity varies inversely as the distance from its center.

The intensity of the magnetic field at any point is proportional to the m.m.f. acting at that point and inversely proportional to the length of its circular path (magnetic reluctance). Thus at the surface of the

TABLE I—RESISTANCE PER 1000 FEET

OF COPPER CONDUCTORS AT VARIOUS TEMPERATURES

STRANDED CONDUCTORS

B & S NO.	AREA CIRCULAR MILS	OHMS PER 1000 FEET OF SINGLE CONDUCTOR															
		ANNEALED COPPER 100% CONDUCTIVITY								HARD DRAWN COPPER 97.3% CONDUCTIVITY							
		0°C 32°F	15°C 59°F	20°C 68°F	25°C 77°F	35°C 95°F	50°C 122°F	65°C 149°F	75°C 167°F	0°C 32°F	15°C 59°F	20°C 68°F	25°C 77°F	35°C 95°F	50°C 122°F	65°C 149°F	75°C 167°F
	2 000 000	00487	00518	00528	.00539	.00559	00591	.00623	.00643	00500	00533	00544	.00554	.00574	00607	.00640	.00660
	1 900 000	00512	00546	00556	.00568	.00590	00623	.00656	.00678	00526	00561	00570	.00574	.00606	.00640	.00674	.00697
	1 800 000	.00541	00577	00588	00599	.00622	00657	.00692	00716	00556	00593	00605	.00615	.00640	00675	.00711	.00735
	1 700 000	00573	00610	00622	.00635	.00659	00695	.00733	.00758	00590	00626	00640	.00652	.00677	.00714	.00753	.00780
	1 600 000	.00609	00647	00660	.00674	00700	00740	.00779	.00805	00626	00665	00678	.00693	.00720	.00760	.00800	.00827
	1 500 000	00650	.00690	00704	00719	.00746	00787	.00830	.00858	00668	00709	00724	.00739	.00766	00808	.00853	.00882
	1 400 000	00696	00741	00755	.00771	.00800	00845	.00890	.00920	00715	00761	00775	.00792	.00822	00868	.00915	.00945
	1 300 000	00749	00798	00813	.00830	.00862	00910	.00958	.00990	00770	00820	00836	.00853	.00885	00935	.00985	.0102
	1 200 000	00812	00864	00880	.00899	00933	00985	0104	.0107	00835	.00888	00905	.00924	.00958	0101	.0107	.0110
	1 100 000	00886	00942	00960	.00981	.0102	0108	0113	.0117	00910	00968	00986	0101	0105	0111	0116	0120
	1 000 000	.00974	.0104	.0106	.0108	0112	0118	0125	0129	0100	0107	0109	.0111	0115	0121	0128	0132
	950 000	0102	0109	0111	0114	0118	0124	0131	0135	0105	0112	0114	0117	0121	0127	.0134	0138
	900 000	0108	0115	.0117	0120	0124	0131	0138	0142	0111	0118	0120	0123	0127	0134	0142	0146
	850 000	0115	0122	0124	0127	0132	0139	0147	0152	0118	0125	0127	0130	0135	0143	.0151	0156
	800 000	0122	0130	0132	0135	0140	0148	0156	0161	0125	0133	0136	0139	.0144	0152	0160	0165
	750 000	0130	0138	0140	0144	0149	0157	0166	0171	0134	0142	0144	0148	0153	0161	0170	0 75
	700 000	0139	0148	.0151	0154	0160	0169	0178	0184	0143	0152	0155	0158	0164	0173	.0183	0189
	650 000	0150	0160	0163	0166	0172	0182	0192	0199	0154	.0164	0167	0170	0176	0187	0197	0204
	600 000	0162	0173	0176	0180	0187	0197	0208	0215	0166	0178	.0181	0185	0192	0202	0214	0221
	550 000	0177	0188	0191	0196	0203	0214	0226	0234	0182	0193	0196	0202	0209	0220	0232	0240
	500 000	0195	0207	0211	0216	0224	0236	0249	0258	0200	0213	0217	0222	0230	0242	0256	0265
	450 000	0216	0230	0234	0240	0249	0263	0277	0286	0222	0236	0240	0247	0256	0270	0285	0294
	400 000	0243	0259	0264	0270	0280	0296	0311	0322	0250	0266	.0271	0277	0288	0304	.0319	0331
	350 000	0278	.0297	0303	0308	0319	0337	0356	0368	0286	0305	0312	0316	.0328	0346	0366	0378
	300 000	0324	0346	0353	0360	0373	0394	0415	0428	0333	0356	0363	0370	0383	0405	0427	0440
	250 000	0390	0415	0423	0432	0448	0473	0498	0515	0400	0426	0435	0444	0460	0487	0512	0530
0000	211 600	0460	.0490	0500	0510	0529	0559	0589	0609	0473	0503	0514	0525	0544	0573	0605	0626
000	167 772	0580	0618	0630	0644	0668	0706	0742	0767	0596	0635	0648	0662	0687	0725	0762	0788
00	133 079	0732	0778	0795	0811	0841	0888	0936	0967	0752	0800	0815	0834	0865	0900	0962	0995
0	105 560	0922	0982	100	102	106	112	118	122	0948	101	103	105	109	115	121	125
1	83 694	116	124	126	129	134	141	149	154	119	127	129	132	138	145	153	158
2	66 358	147	156	159	163	.169	178	188	194	151	160	163	167	173	183	193	.199
3	52 624	185	197	201	205	213	225	237	245	190	202	207	211	219	231	244	252
4	41 738	233	248	253	259	269	284	298	308	239	255	260	266	276	292	306	.316
5	33 078	294	.314	320	327	339	358	376	388	302	323	328	336	348	368	386	.399
6	26 244	371	395	403	412	427	452	475	491	381	406	415	423	438	464	488	.504
7	20 822	468	497	507	519	538	569	598	618	482	512	520	533	553	585	615	635
8	16 512	590	628	640	654	678	716	755	781	607	646	658	672	697	736	.775	802
SOLID CONDUCTORS																	
0000	211 600	0451	0480	0490	0500	0519	0548	0577	0596	0463	0493	0503	0514	0533	0563	0592	0612
000	167 772	.0569	0606	0618	0630	0654	0691	0727	0752	0585	0623	0635	0647	0672	0710	0746	0772
00	133 079	0718	0764	0779	0795	0826	0871	0917	0948	0738	0785	0800	0817	0850	0895	0942	0974
0	105 560	0905	0963	0983	.100	104	110	116	120	0930	0988	101	103	107	113	119	123
1	83 694	114	121	124	126	131	139	146	151	117	124	127	129	.134	143	150	155
2	66 358	[illegible]44	153	156	.159	165	175	184	190	148	157	160	163	.170	.180	189	.195
3	[illegible]2 624	[illegible]81	193	197	201	209	220	232	240	186	198	202	207	215	.226	238	246
4	[illegible] 738	229	244	248	253	263	278	293	302	235	250	255	260	270	.286	301	310
5	33 088	289	307	313	319	331	350	368	381	297	315	321	328	340	360	378	391
6	26 244	364	387	395	403	418	442	465	481	374	398	407	415	430	454	477	494
7	20 822	459	488	498	508	528	557	586	606	472	502	512	523	543	572	602	623
8	16 512	579	616	628	640	665	702	739	764	595	633	645	657	685	722	.759	785

values for the stranded conductors

conductor the m.m.f. reaches its maximum because all of the current of the conductor is acting to produce m.m.f. at this and all points beyond. On the other hand the circular path subject to this maximum m.m.f. is shortest at the surface, the reluctance a minimum and consequently the field intensity is greatest. For points beyond the surface the length of the circular path through air is proportional to the distance from the center of the conductor. Thus at a distance of 2 from the center the circular path is twice as long as at

TABLE II—RESISTANCE PER MILE

OF COPPER CONDUCTORS AT VARIOUS TEMPERATURES

STRANDED CONDUCTORS

B & S No.	Area Circular Mils	Ohms per Mile of Single Conductor															
		Annealed Copper 100% Conductivity								Hard Drawn Copper 97.3% Conductivity							
		0°C 32°F	15°C 59°F	20°C 68°F	25°C 77°F	35°C 95°F	50°C 122°F	65°C 149°F	75°C 167°F	0°C 32°F	15°C 59°F	20°C 68°F	25°C 77°F	35°C 95°F	50°C 122°F	65°C 149°F	75°C 167°F
	2 000 000	.0258	0274	0279	0285	.0295	0312	0329	0340	0265	0282	0288	.0293	.0304	0321	0337	0349
	1 900 000	.0271	0289	.0294	0301	0312	0330	0347	0359	0278	0296	.0301	.0304	0320	0338	0356	.0368
	1 800 000	.0286	0305	0311	0317	.0329	0347	.0366	0379	0294	0314	0320	.0325	0338	.0357	0375	.0389
	1 700 000	.0303	0323	.0329	0336	.0348	0368	0388	0400	.0312	.0331	0339	.0344	.0358	0377	0398	0412
	1 600 000	0322	.0342	0349	0357	.0370	.0391	0412	0425	.0331	0352	0358	0367	.0381	.0402	0422	.0438
	1 500 000	.0344	0365	0373	0380	.0394	0417	0438	0454	.0353	0375	0382	0391	.0405	0427	.0451	.0467
	1 400 000	.0368	.0391	0399	0408	.0423	0447	0470	0487	.0378	0402	0410	.0418	0435	.0459	.0484	.0500
	1 300 000	.0396	.0422	0430	0439	0456	0482	0507	0523	.0407	0433	0442	0451	0468	.0495	0521	.0539
	1 200 000	0429	0457	0465	0475	0493	0520	0550	0565	0442	0470	0478	0489	0507	.0534	0565	0582
	1 100 000	0467	0498	.0507	0518	0539	0572	0597	0618	0482	0512	0521	.0533	.0555	0587	0615	.0634
	1 000 000	.0515	0550	0560	0570	0592	0623	0660	0682	0528	0565	0577	.0587	.0608	0640	0675	.0699
	950 000	.0538	.0577	0587	0603	0624	0656	0693	0713	0555	0593	0603	0618	0640	0672	0710	0730
	900 000	.0571	0608	0618	0635	0655	.0693	0730	0751	0587	.0623	0635	0650	0672	.0708	0750	0772
	850 000	.0608	.0645	0655	0672	0698	0735	0778	0803	0623	.0660	0672	.0688	.0713	0755	0795	0825
	800 000	.0645	0687	0698	0713	0740	0783	.0825	.0851	0660	0703	0718	0735	.0762	.0803	0845	.0873
	750 000	.0688	.0729	0740	0761	0788	0830	0878	0905	0708	0751	0762	0782	.0808	0850	0900	0925
	700 000	0735	0783	0798	0814	.0846	0894	0940	0973	0756	0803	0819	.0835	0866	0915	0965	.100
	650 000	0793	0846	0861	0878	.0910	0962	102	105	.0815	.0867	0883	.0900	0930	.0990	104	108
	600 000	.0857	.0915	0930	0952	.0988	.104	110	114	0878	0940	0957	.0978	102	.107	113	117
	550 000	.0935	0995	101	104	.107	113	121	124	0963	102	.104	.107	.111	116	122	127
	500 000	.103	110	112	.114	.119	125	132	136	106	113	115	117	.122	128	135	140
	450 000	114	122	.124	127	132	139	.146	151	118	125	.127	131	136	143	150	156
	400 000	.129	137	140	143	148	157	165	170	132	141	144	147	152	.161	.168	175
	350 000	147	157	160	.163	169	.178	.188	195	151	162	165	167	174	183	.193	200
	300 000	171	183	187	.190	197	208	.220	.226	176	188	192	.196	203	214	226	.233
	250 000	206	219	224	228	237	250	263	272	211	225	230	235	.243	258	270	.280
0000	211 600	243	259	264	269	.280	296	311	322	249	266	272	277	.288	303	320	.330
000	167 772	306	326	333	341	353	372	392	405	315	335	342	350	363	383	402	.416
00	133 079	387	412	.420	428	444	.470	495	512	398	423	432	.442	457	476	510	527
0	105 560	488	520	528	540	560	.592	624	645	502	535	545	555	.576	608	640	661
1	83694	612	655	.665	682	708	745	787	815	630	672	.682	697	730	766	810	835
2	66358	777	.825	840	862	895	942	995	103	798	845	.862	883	.915	.968	1.02	1.05
3	52624	978	104	107	109	113	119	125	130	101	107	110	112	1.16	122	129	1.33
4	41738	123	131	134	137	1.42	151	158	163	1.27	1.35	138	1.41	146	155	1.61	1.67
5	33078	156	1.66	169	173	180	189	199	205	160	171	173	1.78	1.84	1.95	204	211
6	26244	196	209	213	217	226	239	251	259	201	214	2.20	2.24	232	2.45	258	266
7	20822	248	263	2.68	2.74	284	301	316	327	255	271	275	282	2.93	309	3.25	335
8	16512	3.12	332	338	346	358	3.78	3.99	413	321	341	348	3.55	3.69	389	4.10	4.24
	SOLID CONDUCTORS																
0000	211600	238	254	259	264	.274	289	305	315	245	261	.266	.272	282	.298	312	.323
000	167772	301	320	327	333	346	365	384	397	309	329	336	.342	355	.375	395	408
00	133079	380	404	412	420	436	460	485	501	390	.415	423	.432	.450	473	497	515
0	105560	478	509	.520	528	550	582	613	635	492	522	.535	.545	.565	.597	628	650
1	83694	.603	640	.655	666	693	735	772	798	618	655	672	.680	.708	.755	793	820
2	66358	760	808	.825	840	872	925	972	101	783	830	.845	862	.900	.950	100	103
3	52624	955	102	104	106	111	116	123	127	983	105	107	110	114	119	126	130
4	41738	121	129	131	134	139	147	155	160	124	132	135	138	1.43	1.51	159	164
5	33088	153	162	166	169	1.75	185	195	202	157	167	170	173	180	190	200	207
6	26244	1.93	205	209	214	221	233	246	254	198	210	215	220	227	240	252	261
7	20822	243	258	263	269	279	294	310	320	249	265	271	277	287	302	318	329
8	16512	306	326	333	339	351	371	390	404	314	335	341	347	362	382	402	415

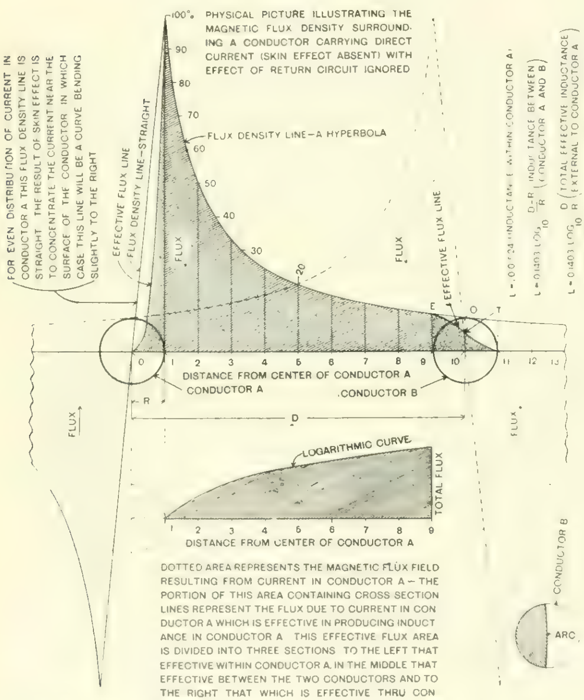
These resistance values do not take into account skin effect. This should be considered when the larger conductors are used, particularly at the higher frequencies. No allowance has been made for increased length due to sag when the conductors are suspended. The resistance values for the stranded conductors are two percent greater than for a solid rod of cross-section equal to the total cross-section of the wires of the cable.

The change of resistivity of copper per degree C. is a constant independent of the temperature of reference and of the sample of copper. This resistivity-temperature constant is 0.0409 ohm (mil, foot). The fundamental resistivity used in calculating this table is the annealed copper standard, viz. 0.15328 ohm (meter, gram) at 20 degrees C.

a distance of *1* (its surface) and consequently, although the m.m.f. is the same the reluctance is double, permitting only one-half as great a flux to flow as at the surface. For a similar reason the density of the field at a distance of *10* is one-tenth the surface density; at *50* it is one-fiftieth, etc. The curve of field density beyond the surface of the conductor therefore assumes the form of a hyperbola.

Inside conductor A the field density is represented by a straight line joining the center of the conductor to the apex of the density curve, represented as 100 percent. Suppose it is desired to determine the field density at a point midway between the center and surface of the conductor. At this point the length of the circular path is one half its length at the conductor surface. Since the current distributes uniformly throughout the cross-section of the conductor, at a point midway between the center and its surface, one-fourth of the total current would be embraced by the circle. The m.m.f. corresponding to this point would therefore be one-fourth its value at the surface. With one-fourth m.m.f. and one-half the surface reluctance the resulting density will be one-half of its surface density as shown by this value falling on the straight line at this distance from the center.

CHART I—INDUCTANCE



FORMULA

TOTAL INDUCTANCE IN MILLIHENRIES (L) PER 1000 FEET OF EACH CONDUCTOR $L = 0.01524 + 0.1403 \log_{10} \frac{D}{R}$

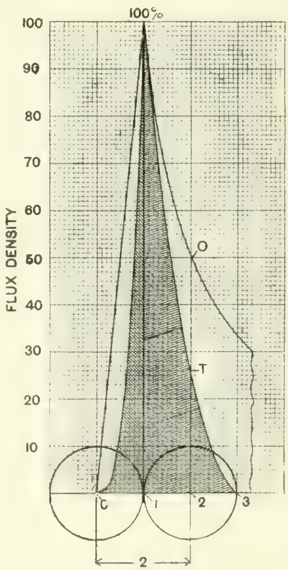


FIG. 6

The m.m.f. resulting from equal currents is the same for all sizes of conductors. Thus the field density at points equally distant from the center of different sizes of conductors carrying equal currents is equal provided these points lie beyond the surface of the larger conductor. For points equally distant from the center of different size conductors which lie inside the conductors the density will be different. Thus if the conductor diameter carrying equal current be reduced to one half, the m.m.f. at its surface will remain the same, but since the flux path at the surface is now only one-half as long, the flux density at the surface will be twice as great. In other words, the magnetic field density at the surface of conductors having different diameters but carrying the same currents is inversely proportional to their radii.

The area indicated by cross-sectional lines on the inductance chart represents the amount of inductance effective in conductor A resulting from current in this conductor. It will be seen that the total area between the adjacent surfaces of the conductors *1* to *9* below the flux density line is effective. This part of the inductance follows a logarithmic curve as illustrated on the chart and is represented by the formula.

$$L = 0.1403 \log \frac{D-R}{R} \quad \ldots\ldots\ldots\ldots (1)$$

Where L is in millihenries per 1000 feet of single conductor.

The effective flux area departs from the flux density line at E dropping down in the form of a reverse curve and terminating in zero at *11*. All flux to the right of *11* cuts the whole of both conductors producing the same amount of inductance in both of them in such a direction as to oppose or neutralize each other.

The flux cutting conductor B from *9* to *11* has its full value of effectiveness in producing inductance in conductor A. On the other hand it also produces to a less extent inductance in conductor B but in a direction to oppose that which it produces in conductor A. The difference between that produced in conductors A and B is the effective flux producing inductance in the circuit and is represented by the shaded portion through conductor B within the area *E-9-11-T-E*. To illustrate how the effective flux curved line *E-T-11* was determined, suppose it is required to determine the effective flux at the distance *10* (center of conductor B). At this point the flux density is ten percent, but since these flux density lines are actually concentric circles, having their center at the middle of conductor A this flux density curve cuts conductor B in the form of an arc (see lower right hand corner of inductance chart). The area of the shaded portion between the two arcs is a measure of the inductance in conductor B at its center. The difference between this shaded area, and the whole area of B, or the clear part to the right of the shaded portion, is a measure of the difference in inductance of the two conductors. In other words, for the spacings shown, approximately 55 percent of ten or 5.5 percent is the value of the effective flux at distance of *10* from conductor A.

If in place of $L = 0.14037 \log_{10} = \frac{D-R}{R}$ .... (1)

we take $L = 0.14037 \log_{10} \frac{D}{R}$ .... (2)

we include all of the inductance area out to the vertical line *O-10*. This would include the area *E-O-T* but not the area *T-10-11*. Since these two areas are equal, the omission of one is balanced by including the other and therefore formula (2) correctly takes into account all of the effective inductance beyond the surface of conductor A.

The inductance within conductor A is determined as follows:—At a point midway between the center and its surface the flux density is 50 percent as indicated by the straight flux density line of the chart. However at this point only one-fourth of the conductor area is enclosed, so that, measured in terms of its effect if outside the conductor, its effectiveness would be only one-fourth of 50 or 12.5 percent. This is the reason that the so-called effective flux line is curved and falls to the right of the straight flux density line. The area of the triangular section *O-1-100* is a measure of the effective inductance within conductor A. This is a constant for all sizes of solid conductors and is represented by the constant 0.01524 of the inductance formula based upon 1000 feet of conductor.

The fundamental formula for the total effective inductance (within and external to conductor A) of a single solid non-magnetic conductor suspended in air is therefore:

$$L = 0.01524 + 0.14037 \log_{10} \frac{D}{R} \text{ per 1000 ft.} \ldots\ldots (3)$$

or

$$L = 0.08047 + 0.74115 \log_{10} \frac{D}{R} \text{ per mile} \ldots\ldots\ldots (4)$$

It may be interesting to note here that the above described graphical solution for inductance produces results in close agreement with these obtained by the fundamental formula for inductance. That is, lay out such a chart on cross section paper to a large scale and count the number of squares or area representing the internal and the external inductance due to current in conductor A. It will be seen that the relative values of the external and internal flux areas conform with the relative values as determined by the formula. This will also be true in the case of the conductors when so placed as to give zero separation, as illustrated by Fig. 6.

VARIATIONS FROM THE FUNDAMENTAL INDUCTANCE FORMULA

It has been proven mathematically by the Bureau of Standards and others that the fundamental formula (3) for determining inductance will give exact results for solid, round, straight, parallel conductors, provided skin and proximity effects are absent. Proximity effect is the crowding of the current to one side of a conductor, due to the proximity of another current carrying conductor. It is similar to skin effect in that it increases the resistance and decreases the inductance. Proximity effect as well as skin effect changes only the inductance due to the flux inside the conductor. Proximity effect is more pronounced for large conductors, high frequencies and close proximity.

For No. 0000 solid conductors at zero separation and 60 cycles, the error in the results (as determined by the fundamental inductance formula) due to skin effect is less than one-tenth of one percent. This error, however, increases rapidly as the size of the conductor increases. Proximity effect cannot be calculated but it is believed to be less than two percent in the above case.

Should skin and proximity effect combined, be sufficient to force all of the current out to within a very thin annulus at the surface of the conductor (a condition obviously never obtained at commercial frequencies) their combined effect would be a maximum. In such a case there would be no inductance within the conductors and the first constant 0.01524 would disappear from formula (3).

Skin and proximity effect are so small in the case of the greater spacings of conductors required for high-tension aerial transmission circuits that they may in such cases be ignored. Even in the case of the close

TABLE III—INDUCTANCE PER 1000 FEET OF SINGLE CONDUCTOR

INDUCTANCE IN MILLIHENRIES (L) PER 1000 FEET OF EACH CONDUCTOR OF A SINGLE-PHASE OR OF A SYMMETRICAL 3 PHASE CIRCUIT. THE TABLE VALUES WERE DERIVED FROM THE EQUATION $L = 0.01524 + 0.1403 \log_{10} \frac{D}{R}$ WHEN R IS THE RADIUS OF CONDUCTOR AND D DISTANCE BETWEEN CENTERS OF CONDUCTORS EXPRESSED IN SAME TERMS AS R. FOR STRANDED CONDUCTORS D WAS TAKEN AS THE DIAMETER OF A SOLID ROD OF EQUIVALENT CROSS-SECTION.

CONDUCTORS					DISTANCE (D) BETWEEN CENTERS OF CONDUCTORS X																									
MATERIAL	TYPE	DIAMETER IN INCHES	B & S GAUGE	AREA IN CIRCULAR MILS	½"	1"	2"	3"	4"	5"	6"	8"	12"	18"	2 FEET	3 FEET	4 FEET	5 FEET	6 FEET	7 FEET	8 FEET	9 FEET	11 FEET	13 FEET	15 FEET	17 FEET	19 FEET	21 FEET	23 FEET	26 FEET
COPPER	STRANDED	[illegible]		2 000 000			079	104	121	135	146	163	188	212	230	255	272	283	296	307	315	322	334	344	352	361	.367	.373	379	.383
		548		1 800 000			082	107	124	138	149	166	191	215	233	258	276	289	300	309	317	325	.338	.347	355	364	.370	377	.382	.387
		504		1 700 000			084	109	126	139	151	168	193	217	235	259	277	291	301	311	320	326	.339	349	357	.365	.372	378	.383	388
		459		1 600 000			086	110	128	141	153	170	195	219	237	261	279	294	303	314	321	329	341	351	359	.368	373	.381	385	391
		412		1 500 000			.088	112	130	143	155	172	196	222	238	264	281	295	306	315	323	331	343	353	361	369	376	.382	.388	393
		364		1 400 000			089	114	132	145	156	174	198	223	241	265	283	297	.308	318	325	333	345	355	364	.371	378	384	.390	395
		263		1 200 000			094	119	136	150	161	179	203	227	246	270	288	301	314	322	330	338	350	359	368	377	384	389	.395	399
		209		1 100 000			097	121	139	153	164	181	206	230	248	273	290	305	315	324	333	340	352	362	371	379	385	392	396	403
		152		1 000 000			100	125	142	156	167	184	209	234	251	276	294	307	318	327	336	344	355	365	.374	381	388	394	399	405
		123		950 000			101	126	143	157	168	186	211	235	252	277	295	309	319	329	338	345	356	366	376	384	390	.396	402	.407
		093		900 000			103	128	145	159	170	187	212	236	255	278	296	311	321	330	339	346	.358	368	377	.385	391	398	.404	.408
		062		850 000			105	130	147	161	172	189	214	238	256	281	299	312	323	333	341	348	360	370	379	.386	393	399	405	410
		031		800 000			107	131	149	163	174	191	215	241	258	282	300	314	324	334	343	350	362	372	381	.389	395	401	407	.412
		998		750 000		066	108	133	151	164	176	193	218	243	260	285	302	316	327	337	345	351	364	374	383	390	397	403	.409	414
		964		700 000		068	111	135	153	167	178	195	219	244	262	286	304	318	329	339	347	353	.366	375	385	392	398	405	411	416
		929		650 000		071	113	138	155	169	180	197	222	247	264	289	306	321	331	341	349	356	368	378	387	395	402	407	.413	418
		893		600 000		073	116	140	158	170	182	200	224	249	266	.291	309	322	334	343	352	358	370	380	390	397	403	410	415	420
		855		550 000		076	.118	143	160	173	185	202	227	252	269	293	312	325	337	346	354	361	373	383	392	400	407	413	418	423
		815		500 000		079	121	146	163	176	188	206	230	255	.272	297	315	328	339	347	.357	364	376	386	395	402	409	415	422	426
		772		450 000		082	.124	149	166	180	191	208	233	257	275	300	318	331	342	351	360	367	380	389	398	406	.413	419	425	.430
		728		400 000		086	128	153	170	183	195	213	237	261	279	304	322	335	346	356	363	371	383	393	402	409	417	422	428	.433
		681		350 000		090	.133	157	174	187	199	216	241	266	283	308	326	339	350	360	368	375	387	398	406	413	420	.427	432	437
		630		300 000		094	137	161	179	192	203	220	245	270	288	312	330	343	355	364	372	380	392	402	410	418	425	432	.437	442
		575		250 000		100	.142	167	184	197	209	226	251	276	294	318	336	349	361	369	378	385	397	408	416	425	432	436	441	448
		528	0000	211 600		105	147	172	189	203	214	231	256	281	299	323	341	354	.366	374	383	389	401	412	421	429	435	442	.448	.453
		470	000	167 772	070	112	.154	179	196	210	221	238	263	288	306	330	348	362	373	381	390	396	409	419	429	436	442	449	455	.460
		418	00	133 079	077	119	161	186	203	217	229	245	271	295	313	338	355	369	380	388	397	403	416	426	436	443	450	457	462	467
		373	0	105 560	084	126	168	193	210	224	235	252	278	302	320	345	362	376	387	395	404	411	423	433	443	450	454	463	469	474
		332	1	83 694	091	133	175	200	217	231	242	259	285	309	327	352	370	383	394	402	411	418	430	440	450	458	465	470	477	481
		292	2	66 358	098	140	182	207	224	238	249	266	292	316	334	359	376	390	401	409	418	425	437	447	457	464	472	477	482	488
		260	3	52 624	105	147	189	214	231	245	256	273	298	323	340	365	382	396	407	416	425	432	444	454	463	472	478	485	492	495
		232	4	41 738	112	154	.196	221	238	252	263	280	306	331	348	373	390	404	415	423	433	439	451	461	471	478	485	492	497	502
		206	5	33 088	119	161	203	228	245	259	270	288	312	337	354	379	396	410	421	431	439	446	458	468	477	485	492	499	505	510
	SOLID	460	0000	211 600	062	105	147	172	189	203	214	231	256	281	299	323	341	354	366	374	383	389	401	412	421	429	435	442	448	453
		410	000	167 772	070	112	154	179	196	210	221	238	263	288	.306	330	348	362	373	381	390	396	409	419	429	436	442	449	455	460
		365	00	133 079	077	119	161	186	203	217	229	245	271	295	313	338	355	369	380	388	397	403	416	426	436	443	450	457	462	467
		325	0	105 560	084	126	168	193	210	224	235	252	278	302	320	345	362	376	387	395	404	.411	423	433	443	450	457	463	.469	474
		289	1	83 694	091	133	.175	200	217	231	242	259	285	309	327	352	370	383	394	402	411	418	430	440	450	458	465	470	477	481
		258	2	66 358	098	140	182	207	224	238	249	266	292	316	334	359	376	390	401	409	418	425	437	447	457	464	472	477	482	488
		229	3	52 624	105	.147	189	214	231	245	256	273	298	323	340	365	382	396	407	416	425	432	444	454	463	472	478	485	492	495
		204	4	41 738	112	.154	196	221	238	252	263	280	306	331	348	373	390	404	415	423	433	439	451	.461	471	478	485	492	.497	502
		182	5	33 088	119	.161	203	228	245	259	270	288	312	337	354	379	396	410	421	431	439	446	458	468	477	485	.492	499	505	510
ALUMINUM	STEEL REINFORCED	953		605 000		073	115	140	157	170	182	200	225	248	266	291	309	323	333	343	351	358	.371	.381	.389	397	405	.410	.415	.420
		904		500 000		079	121	145	163	178	188	206	230	255	272	297	315	329	340	.348	.357	365	375	386	395	403	.410	.415	422	.428
		741		336 420		091	133	158	175	188	200	218	242	267	285	309	327	340	351	361	369	375	388	399	407	415	422	428	.433	440
		635		266 800		098	141	165	182	195	207	225	249	274	292	316	335	347	359	367	375	384	395	405	415	422	429	435	.440	.447
		564		211 950		105	147	171	190	202	214	231	256	281	299	323	340	355	365	375	383	.390	401	411	422	430	.437	442	447	453
		501		167 800		112	154	179	196	210	221	239	264	287	305	331	347	361	373	382	390	397	410	420	429	.437	.443	449	455	460
		447		133 200	077	119	161	186	204	216	228	246	271	295	313	337	354	369	379	389	397	405	417	427	435	445	450	457	.462	467
		398		105 530	084	126	169	192	210	225	235	252	278	302	320	344	362	375	386	396	405	411	425	435	443	450	.458	464	469	.475
		355		83 640	091	133	175	200	217	232	242	260	285	309	327	351	367	382	393	404	410	420	430	441	450	457	465	.470	475	480
		316		66 370	098	140	182	207	224	239	249	267	291	316	335	358	375	389	400	411	418	425	437	448	457	465	472	.477	485	.487
		281		52 630	105	147	189	213	231	245	256	274	299	324	341	365	383	397	.407	417	425	.433	445	455	465	471	.477	485	.490	495
		250		41 740	112	154	197	221	239	253	264	281	306	331	347	373	389	404	415	425	433	440	452	462	471	478	485	492	.497	502

A	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175	180	185	190	195	2.00
B	003	006	008	011	014	016	018	020	023	025	027	029	030	.032	034	.036	037	039	.041	042

X The inductance for any distance D not given in the table can be found as follows: Let E = the nearest smaller distance in the table. Divide D by E and, taking a value of A nearest to the quotient, find the corresponding value of B which must be added to the inductance corresponding to the size of conductor and distance E.

For three phase regular flat spacing use D = 1.26 A. For three phase irregular flat or triangular spacing use $D = \sqrt[3]{ABC}$. For a two-phase line the spacing is the average distance between centers of conductors of the same phase.

spacings required for three conductor cables these combined effects are usually less than four percent.

EFFECT OF STRANDING ON INDUCTANCE

The fundamental formula (3) for determining inductance is based upon a solid conductor, R being taken as the radius of the conductor. In stranded cables the effective value for R lies between the actual radius and that of a solid rod having an equivalent cross-section to that of the cable. The effective value for R varies with the stranding of the cable employed.

Formulas for use in determining the inductance of stranded cables when used for high-tension aerial transmission have been calculated by Mr. H. B. Dwight as follows:

For a 7-wire cable, $L = 0.741 \log_{10} \frac{2.756\ D}{d}$ ...... (5)

For a 19-wire cable, $L = 0.741 \log_{10} \frac{2.640\ D}{d}$ ...... (6)

For a 37-wire cable, $L = 0.741 \log_{10} \frac{2.605\ D}{d}$ ...... (7)

For a 61-wire cable, $L = 0.741 \log_{10} \frac{2.590\ D}{d}$ ...... (8)

where L is in millihenries per mile of a single conductor, D is the spacing between centers of cables, and d is the outside diameter of the cables measured in same units as D.

SPIRALING EFFECT UPON INDUCTANCE

Spiraling of the strands of a cable and spiraling of the conductors of a three-conductor cable tend to increase the inductance. It is difficult to calculate the effect of spiraling for the various cases, but it may be considered negligible for high-tension aerial transmission circuits using non-magnetic conductors. For three-conductor cables the effect of spiraling is probably in the neighborhood of two percent.

Values for inductance per thousand feet of single conductor are given in Table III, for commercial sizes of copper and steel reinforced aluminum conductors. The formula by which the values were derived are:—

$$L = 0.01524 + 0.1403 \log_{10} \frac{D}{R} \ \dots\dots\dots\dots\dots\dots (3)$$

where L = Millihenries per 1000 feet of single conductor of a single phase, or of a symetrical three-phase circuit.
D = Distance between centers of conductors.
R = Radius (to be measured in same units as D) of solid conductor. In the case of stranded conductors, R was taken as the radius of a solid rod of equivalent cross-section to that of the stranded conductors.

Table III has been carried out to three figures only. This would seem sufficiently accurate for working values when it is considered that there are numerous sources of variation from the calculated values. In the first place formulas are based upon a uniform distribution of current throughout the cross section of the conductors, whereas the current is seldom uniform and in the larger conductors, especially at 60 cycles, may be to a large extent crowded to the outer strands as a result of skin effect. This condition is further modified when the conductors are placed close together, by the proximity effect. Stranded conductors made up of various stranding combinations result in variation of inductance of several percent. In practice the length and spacing of conductors will vary more or less from those assumed when determining the calculated values.

The values for inductance of stranded conductors in Table III, as stated above, were derived by taking R as the radius of a solid rod having an equivalent cross-section area to that of the stranded conductors. Thus for 1 000 000 circ. mil cable the outside diameter is 1.152 in. and that of an equivalent solid iron is 1.0 in. R was therefore in this case taken as 0.5 in. The effective radius is really slightly greater than that of the solid rod and less than that of the cable, varying with the stranding employed. The actual inductance of cables will therefore be slightly less (usually two or three percent) than those indicated in the table for solid rods. The table values are therefore conservative.

The steel core of steel reinforced aluminum cables carries so little current on account of its relatively greater resistance that for practical purposes it has been customary to ignore its presence and to consider such conductors as solid rods of same area as that of the aluminum strands. In the absence of accurate data this practice was followed in determining the values for inductance of such cables in Table III.

The minimum value for inductance occurs when the conductors have zero separation $\frac{D}{R} = 2$, (Fig. 6). In this case the inductance in millihenries is independent of the size of the conductor. As given by formula (3) it is $L = 0.05124 + 0.1403 \log_{10} 2 = 0.0575$ millihenries per 1000 feet of each conductor. Obviously insulation requirements will not permit of such a low value for inductance although it will be closely approached in low voltage cables.

Any given percentage difference in distance between centers of conductors represents a definite and constant value in inductance regardless of their size. These values are given in column B at the bottom of the table for various percentages increase in spacings. Thus if the distance between conductor centers is increased 50 percent the corresponding increase in inductance is 0.025 as indicated in column B, under the A values of 1.50. Likewise doubling the distance increases the inductance by an amount of 0.042. For instance the table value for inductance of No. 0 solid copper conductor is for one-half inch spacing 0.084, and for one inch spacing *0.126* (an increase of *0.042*.) For four foot spacing the table value is 0.362, and for eight foot spacing 0.404, also a difference of 0.042.

References:—An article by Prof. Charles F. Scott, "Inductance in Transmission Circuits" in THE ELECTRIC JOURNAL for Feb. 1906 very clearly covers the field of self and mutual inductance external to the conductors.
H. B. Dwight, "Transmission Line Formulas."
V. Karapetoff, "The Magnetic Circuit" p. 189.

Electricity in the World's Largest Hotel

William H. Easton

THE recently opened Hotel Pennsylvania, which adjoins the Pennsylvania Terminal, New York City, is of special interest from an electrical standpoint because it is not only the largest in the world but is also one of the most magnificent, and was planned to be second to none in comfort and convenience. No expense was spared that would add to the excellence of its construction or improve its service to guests, and in consequence its electrica equipment may be regarded as representing the highest type of installations of this character.

FIG. 1 HOTEL PENNSYLVANIA
Seventh Ave., 32nd & 33rd Streets, New York City.

FEATURES OF THE HOTEL SERVICE

A detailed description of the hotel itself would be out of place here, but some of its most unusual features will be of interest. There are altogether 2200 bed rooms, and each has a fully equipped bath. All rooms are on the outside, and as the plan of the bed-room floors resembles an E with its vertical stroke facing north, most of the rooms have a southerly exposure.

FIG. 2 LOBBY

The interior decorations are, like the exterior, simple but handsome. The great lobby resembles a Roman atrium with its marble columns, classical ornamentation and beautifully stained glass skylight. The architectural styles of the other concourse rooms are equally simple, the main restaurant, grill room and ball room being reminiscent of the early Italian renaissance and the men's cafe being Georgian in character. The bed room walls have neither pictures nor wall paper, but are finished in soft monotones. The furniture, rugs, hangings, lighting fixtures, and even the silverware are in harmony with their surroundings and gain their atttactiveness mainly through their pleasing lines and proportions.

The rooms are equipped with a number of novel conveniences, such as running ice water and lights at the heads of the beds, but the most striking is found in the doors to the rooms. The door used is called the "servidore" and differs from the ordinary door in having a hollow interior which forms a closet about six inches deep and about five feet high. A supplementary door on each side permits access to this closet from both the room and the hall. If, for example, a guest wishes to have a suit pressed, he places it within the servidore and phones the hotel central. The next morning he finds it there cleaned and pressed, as the attendant has removed it from the hall side, given it to the tailor, and later replaced it. In the same way breakfast, newspapers, and almost everything else desired by the guest can be supplied him without the inconvenience of having to open the door and admit the hotel attendant. A signal shows when the article ordered is in the servidore.

Among the other features of the hotel service are:—two Turkish baths and plunges, one for men and one for women; a small kitchen on every bedroom floor for the quick preparation of breakfasts to be served in rooms; a bedroom floor reserved solely for women; a combination ice-skating rink and dancing floor; a hospital in which major operations can be performed; a well stocked library; a telautograph system for transmitting orders and messages from the hotel central to the various departments; and last, but not least, the absence of disturbing noises, due to the use of sound proof floors and walls and the careful selection of all the machinery in the hotel.

THE POWER SUPPLY

Under ordinary circumstances power from the local central station would undoubtedly have been used to supply this hotel, if for no other reason than to eliminate the smoke, dirt, coal, ashes and noise unavoidable with a private plant. But as the Pennsylvania Railroad

has two large power houses in the immediate vicinity—one in Long Island City for train operation and the other in the Pennsylvania Terminal to serve that building—the hotel is naturally supplied with power from these stations. Hence though not on the lines of a central station, the hotel is actually an excellent example of central station practice.

FIG. 3—BALL ROOM

The Long Island City Power Plant is connected with the terminal plant, so that the hotel has the benefit of two independent sources of supply. Power is furnished in the form of three-phase, 60-cycle, 11 000 volt, alternating current and is transmitted by cables in a deep underground tunnel running from the terminal plant to the transformer room of the hotel.

In addition to this supply of power, there is also a 500 kw, 240 volt direct-current Westinghouse generator driven by a 24 by 42-inch Hamilton-Corliss engine located in the engine room of the hotel. This generator serves two purposes; it provides a third source of power in case of the remote possibility of a failure of the alternating-current supply, but more particularly it acts as a reducing valve for the steam supply. There are no boilers in the hotel, as the steam is furnished by the terminal plant at 150 pounds pressure. To reduce this pressure to that required for steam heating by means of a valve would obviously involve waste of energy. By driving the generator with this high-pressure steam and using the exhaust for heating purposes the current obtained can be estimated as costing little more than the overhead expenses. The unit runs at 120 r.p.m. and operates so quietly that only the click of the valve gear can be heard. It is shut down in summer when steam heat is not needed

THE TRANSFORMERS

As is shown in the plan of the sub-basement floor, Fig. 4, the transformers are located in a small room which is completely shut off from the engine room by thick brick walls. It contains three banks of three

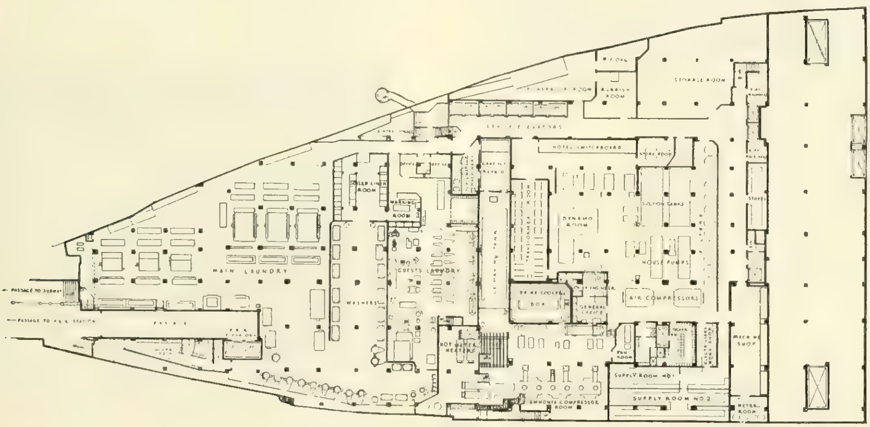


FIG. 4—PLAN OF SUBBASEMENT

The triangular shape is due to the fact that the Long Island Railroad Tunnel cuts through diagonally at this level.

transformers each, consisting of 187 k.v.a. transformers, and two each of three 250-k.v.a. transformers. The first three banks supply three Westinghouse rotary converters and the other two supply the lighting system. Electrically-operated oil circuit breakers control the high-tension lines, and disconnecting switches permit one or more of the transformers to be cut out without interfering with the operation of the others.

THE DIRECT-CURRENT SYSTEM

The electrical distributing system is divided into two separate parts:—(1) a direct-current system for motors driving elevators, ventilating fans, and other machinery requiring speed control, and (2) an alternating current system for lighting, cooking, and miscellaneous applications.

The direct current is obtained from the generator and the three rotary converters. These four machines

FIG. 5—TRANSFORMER ROOM
Nine 187 k.v.a. transformers for rotary converters, at 11 000 to 188 and 58 volts. Six 250 k.v.a. transformers for lighting at 11 000 to 250 and 125 volts, all three-phase, 60 cycles.

are arranged so that any combination of them can be operated in parallel and, as the present load can readily be handled by any two of them, there is ample reserve capacity. Provision is made for a fourth converter if future requirements demand it.

The rotary converters are of 500 kw capacity each and supply direct current for 240 volt two-wire circuits. Their bank of transformers supplies them with 58 volt current for starting and 188 volt current for running. An individual starting switch is mounted on a panel beside each converter. Two small motor-generator sets (one being a spare) furnish the excitation current for the converters.

The average direct-current power load is 450 amperes with occasional peaks of 600 amperes. The total average 24 hour load is about 5000 kilowatt-hours and it is estimated that this will be increased to about 6000 kilowatt-hours.

THE ALTERNATING-CURRENT SYSTEM

The secondaries of the two banks of lighting transformers supply alternating current for 240/120-volt three-wire circuits. The two banks are independent and at present either one can supply the ordinary de-

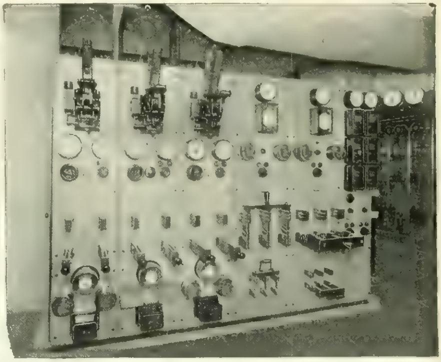


FIG. 6—MAIN POWER SWITCHBOARD
The three left hand panels are for the rotary converters. The next two panels are for the main lighting circuits and the right hand panel carries the high voltage instruments and relays.

mand of the hotel, which amounts to about 500 kw maximum. At present the 24 hour lighting load averages about 8000 kilowatt-hours, which will be increased to at least 9000 kilowatt-hours later on.

THE SWITCHBOARDS

There are two switchboards in the hotel engine room, both of Westinghouse make. One called the power board is of six panels, of which the first three handle the direct current from the three converters; the next two, the main circuits from the two banks of lighting transformers; and the last carries the high tension

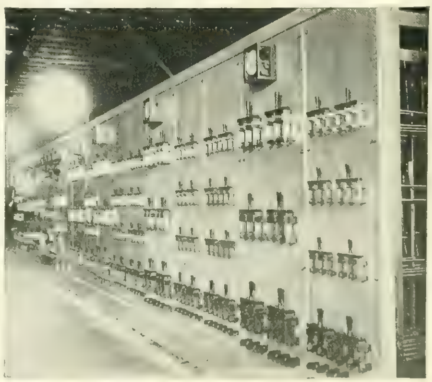


FIG. 7—DISTRIBUTING PANELS

instruments and relays. Both the rotary converter circuits and the lighting circuits pass from the power board directly to the second board.

The second switchboard is the main distributing board. It consists of 21 panels and is divided into three

sections; the power section, the power distributing section and the lighting distributing section. The power-receiving section carries the various instruments needed to control the generator and the exciters for the rotary converters and to parallel and distribute the various direct-current circuits. The power-distributing section

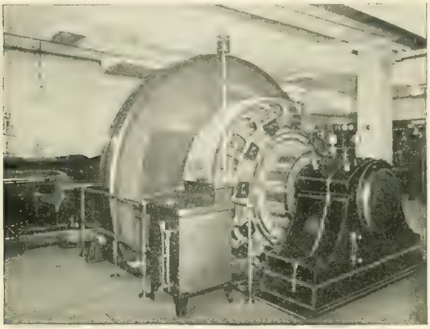


FIG. 8—500 KW, 120 R.P.M. DIRECT-CURRENT GENERATOR
Driven by a 24 by 32 inch Hamilton Corliss engine, with a 59 000 lb. flywheel.

carries switches which control the various power circuits throughout the hotel. Local control of the elevators and ventilating fans located on the roof is supplied by two distributing boards in the pent house on the roof, and a third distributing board on the fourth floor controls all the other power circuits above that floor. The lighting-distributing section receives current from either or both of the two banks of lighting transformers (according to the switch arrangement on the power board) and controls all the lighting circuits.

THE LIGHTING SYSTEM

The three phases of the lighting system are distributed so that an approximate balance is secured. A

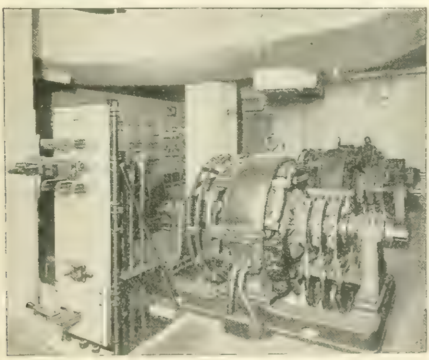


FIG. 9—ROTARY CONVERTER SUBSTATION

feature of the arrangement is that all lights needed in an emergency, such as those in the corridors, at the elevators, etc., are operated on a special circuit which can be supplied with direct current immediately in case the alternating-current should fail, thus preventing the plunging of the hotel into darkness at a critical moment.

The lighting of the concourse rooms is primarily artistic in its purpose. The fixtures are of special design, to harmonize with the decorations, while the lights are shaded to produce certain color effects, a deep tone of orange being used in some rooms, rose in others and white in others. The lighting of the stained-glass skylight of the lobby received particular attention and, by the use of a large number of lamps equipped with X-ray beehive reflectors, an effect of diffused sunlight has been closely approximated. A similar skylight is used in the ball room. Semi-direct fixtures, supplemented by side and bedstead lamps, are used in the bedrooms. Twenty-two thousand Westinghouse type C lamps of a large range of sizes were needed for the initial installation.

The lighting panels throughout the hotel are of the Krantz safety type. Each panel has two doors, one

FIG. 10—KRANTZ SAFETY LIGHTING PANEL IN BALL ROOM
With doors unlocked and open for inspection or fuse renewal.

within the other. The inner door covers the switches for the various circuits and every part that can be reached when this door is open is electrically dead so that it is impossible to get a shock when operating the switches. The second door, which cover the fuses, is kept locked and can be opened by authorized electricians only. There are about 200 of these panels in the hotel.

VENTILATION

The system of ventilation is very complete. Practically all of the rooms in the three basements and the first four floors are supplied with fresh, filtered, washed and tempered air by blowers, and are freed from foul air by exhausters, while all of the 2200 bath rooms are ventilated by means of exhaust.

There are 27 Sturtevant multivane ventilating fans in all. The blowers are located in the basements and lower floors while the exhausters are for the most part on the roof. Each fan is direct-connected to a West-

inghouse slow-speed motor, with a speed range of from 1 to 1½ or 1 to 2 by field control. Quiet operation was made essential to the acceptance of these motors and as a matter of fact they are so noiseless that it is

FIG. 11—EXHAUST FAN SERVING BATH ROOM EXHAUST
Driven by a 38 hp, 135-200 r.p.m. adjustable speed direct-current motor.

impossible to tell from the sound whether they are running or not. A total of 750 horse-power ventilating motors is used.

ELEVATORS

The elevator equipment consists of twelve passenger and eight service elevators, that reach all floors, and four passenger and three service elevators that have short special runs. All except one large service elevator are of the 1 to 1 gearless traction type and run at 600 feet per minute. The large service elevator is of the worm-gear traction type and runs at 450 feet a

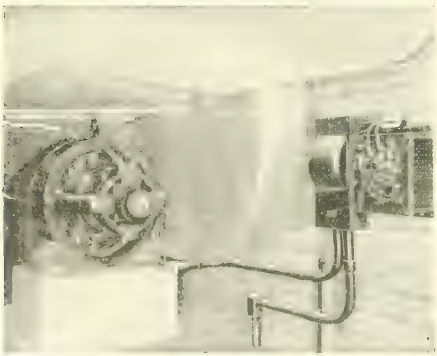


FIG. 12—[illegible] EXHAUSTER [illegible] ENGINE ROOM
Driven by a [illegible] 350 r.p.m. adjustable speed direct-current motor.

minute. There is also a bank of six dumb-waiters, with a capacity of 100 pounds each and a speed of 500 feet per minute, furnishing service between the main kitchen and the breakfast kitchens.

SERVICE PUMPS

The hotel has two water tanks, one on the eleventh floor and the other on the roof, which are supplied by steam pumps in winter and electric pumps in summer. The electric pump for the lower tank is a two-stage centrifugal, driven by a 60-hp, 1600-r.p.m. Westinghouse motor. That for the upper tank has four stages and is driven by a 100 hp, 1200 r.p.m. motor Both pumps are equipped with automatic float controllers and are rated at 800 gallons per minute. They take water from an open tank supplied from the city water mains. The high pressure pump operates against a static head of 175 pounds and the low pressure against 100 pounds. The fire pumps are steam operated.

REFRIGERATING SYSTEM

Refrigeration is produced by three 65-ton steam driven York ammonia compressors and is used for the following purposes:—

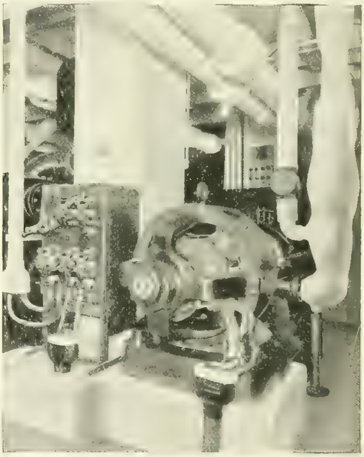


FIG. 13—FOUR STAGE CENTRIFUGAL PUMP SERVING TANK ON 22ND FLOOR
Driven by a 100 hp, 1200 r.p.m. direct-current motor with automatic float control.

To keep cold about 150 refrigerator boxes in the main kitchens, breakfast kitchens, suite kitchenettes and other places throughout the hotel; to provide cold drinking water in every bedroom; to freeze and preserve ice cream, and to make ice.

For supplying the refrigerator boxes, cold brine (ammonia is not used above the basement floors) is pumped by two systems of duplicate steam and electric pumps. The high-pressure system has a static head of 200 pounds, which is higher than in the corresponding house service system because of the greater specific gravity of the brine. The brine is circulated by a three-inch centrifugal pump of 150 gallons per minute capacity against a friction head of 140 ft. and driven by a 15 hp. direct-current Westinghouse motor, with a speed range of 850 to 1650 r.p.m. by field control. The circulating pump for the low-pressure brine sys-

tem, which serves every thing below the first floor (static head, 50 lbs.) is a four-inch, 360 gallons per minute centrifugal operating against a friction head of 70 ft. and is driven by a motor similar to that on the high-pressure system. The low pressure system will also take care of the 20 by 34 foot ice skating rink, which is later to be installed under the dancing floor of the grill room.

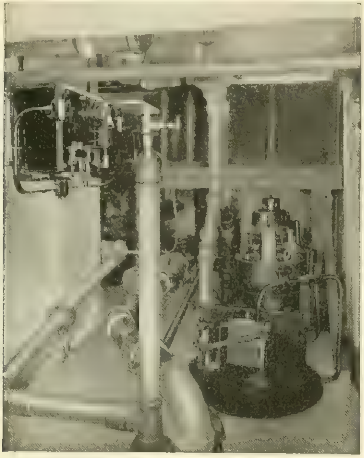


FIG. 14—TWO CENTRIFUGAL SUMP PUMPS
Driven by 7.5 hp, 1600 r.p.m. vertical motors with automatic float control.

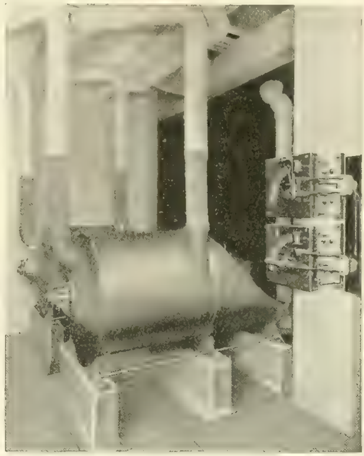


FIG. 15—TWO TEN-STAGE TURBINE VACUUM CLEANERS
Serving a total of 489 outlets. Each machine can handle 30 outlets maximum with a 3 inch vacuum at hose end. Driven by 20 hp, 1750 r. p. m. direct-current motors. The hotel has 3 miles of 3 inch vacuum cleaner piping.

TABLE I.—VENTILATING EQUIPMENT

Fan					Motor		
Type	Service	Size	Width	Inlet	Hp.	Speed Min.	Speed Max.
West Fan Room Sub-Basement Mezzanine							
Exhauster	Cafe and Bar	8	Single	Single	5½	185	275
Blower	West Side Room Basement and Sub Basement Mezzanine	9	Double	Double	30	205	305
Blower	West Side Room	7	Single	Single			
Blower	Grill	9	Single	Single	16	170	335
Blower	Laundry	11	Single	Double	25	155	235
East Fan Room Sub-Basement Mezzanine							
Blower	Kitchen	9	Double	Double	40	225	340
Blower	East Side Rooms of Sub-Basement Mezzanine	10	Double	Double	28	165	250
Blower	Lobby	8	Double	Double	25	195	390
Blower	Dining Room	8	Double	Double	30	209	410
Exhauster	East Rooms of Sub-Basement Mezzanine	9	Double	Double	30	215	320
Sub Basement Fan Room							
Exhauster	Grill Exhaust Machine	7	Double	Double	7	220	330
Blower	Shop Supply Engine Room	10	Double	Double	22	120	235
Second Floor Fan Room							
Exhauster	Ball Room	9	Single	Double	26	145	285
Exhauster	Ball Room	9	Single	Double			
Exhauster	Northeast Banquet Room	8	Single	Single	5½	185	275
Exhauster	Turkish Bath	7	Double	Double	7	220	330
Blower	Turkish Bath	6.5	Double	Double	8	215	425
Pent House Fan Room, Top Floor							
Exhauster	Bath Rooms	10	Double	Double	35	135	265
Exhauster	West Side Rooms	10	Double	Double	45	140	280
Exhauster	Bath Rooms	10	Double	Double	38	175	265
Exhauster	Kitchen	11	Double	Double	45	155	235
Exhauster	Banquet Kitchen	9	Single	Single	13½	200	300
Exhauster	Dining Room	9	Double	Double	35	215	320
Exhauster	Bath Rooms		Double	Double	35	135	265
Exhauster	Laundry	12	Double	Double	45	135	200
Exhauster	Engine Room	10	Double	Double	35	140	280
Exhauster	Bath Rooms	9	Double	Double	21	150	295

The drinking water is supplied from the filters and is pumped by a steam pump into a galvanized iron cooler, where it is cooled to 40 degrees F. by ammonia coils. It is circulated through the hotel by two three-inch, 100 gallons per minute centrifugal pumps, operating against a friction head of 150 ft., each driven by a 7.5 horse-power direct-current Westinghouse motor with a speed range of from 850 to 1700 r.p.m. by field control. Either pump can take care of the system, so that one is a spare. There are about 2300 taps altogether and the static head is 175 pounds.

The ice-cream refrigerating system supplies brine to the freezers and keeps the storage boxes at a temperature of 10 degrees F. The 80 gallon per minute circulating pump operates at a friction head of 70 ft. and is driven by a motor similar to those on the drinking water pumps. The brine system for the entire installation is filled by steam pumps.

The ice-making tank is 55 feet long, 12 feet wide and 4 feet deep, and holds 200 cans of 300 pounds each. The brine agitator is driven by a 2-hp

900-r.p.m., vertical motor, and the cans are handled by an electric hoist. The air for agitating the water in the cans, so as to produce clear ice, is freed from moisture to prevent the air pipes from being closed by frost by passing it through a shell-and-coil dehumidifier containing freezing coils supplied with brine by a pump driven by a one-hp motor.

In the ice crusher room there are,—a cube machine with a capacity of 5000 two-inch cubes per hour, a second one with a capacity of 600 1½ inch cubes per hour and two crushers, one coarse and one fine, each with a capacity of five tons per hour. All four machines are driven by a 7.5 hp, 850 r.p.m. motor.

LAUNDRY EQUIPMENT

The quantity of towels, bed and table linens that are used daily makes it necessary to have a large as

FIG. 16—MOTOR DRIVEN POTATO PEELER

well as an efficient laundry. To handle this enormous quantity the most modern and up-to-date laundry equipment has been installed, making it the largest electrically-driven laundry in the world. The equipment includes ten 42 by 72 inch cascade metallic washers which are driven by direct-connected reversing motors. Twelve 40 inch overdriven centrifugal extractors dry the work, with the exception of bath towels, which are handled in three 40 by 94 inch steam-heated drying tumblers. Ironing is performed with five 120 inch flatwork ironers.

A curtain drier and finisher and complete laundry equipment for handling guests' wearing apparel are also installed. Each machine is driven by its own motor, and panelboard control is used extensively. Although located in the sub-basement, this laundry is very comfortable as a working place because of the effective ventilating system provided.

OTHER MOTOR APPLICATIONS

Motors are also used for operating dish conveyors, dish washers, potato peelers, food choppers, cake mixers, ice cutters, and other machines.

FIG. 17—TWO INCH ICE CUBER, 1.5 INCH ICE CUBER, COARSE CRUSHER AND FINE CRUSHER
Driven by a 7.5 hp, 850 r.p.m. direct-current motor.

ELECTRIC COOKING

Though gas ranges are used in the main kitchens, electricity is extensively employed for cooking. Electric ranges and bake ovens are used exclusively in the kitchen for the men's cafe and in the "home-cooking" kitchen (which is entirely separate from the main kitchen and is in charge of a former housekeeper assisted by former domestic servants). The electric cooking circuit in the home cooking kitchen has an individual meter. This kitchen has 57 kw in ranges and

FIG. 18—DISH CONVEYER
For carrying the dishes from the dining rooms to the dishwashers. Operated by a one-half horse-power direct-current motor.

bake ovens. The average use of power is 120 kw-hrs. per day. The bedroom floor breakfast kitchens are provided with electric hot plates, toasters, coffee percolators, egg boilers, etc., and the kitchenettes attached to the private suites are similarly equipped.

Electrical Equipment Used on Submarines

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The important part that electricity and electrical apparatus takes in the operation of a modern submarine is not generally appreciated. It is the purpose of this article to outline, in a more or less general way, the entire electrical equipment required by one of our newest types of submarines, without going into close detail regarding the operation of the less important pieces of apparatus.

THE FIRST known submarine boat was built in 1624 and operated by a Hollander by the name of Van Drebbel. It was simply a wooden boat with a covering of leather and propelled by oars. In 1772 David Bushnell of this country invented and built the first submarine to be actually used in warfare. His boat was large enough to accomodate only one man, and carried a torpedo on the outside, to be attached to the enemy's ship by means of a screw. It was driven by a screw propeller operated from a hand crank, and carried a small hand pump to handle the water ballast used for submerging. Although quite successful, the boat was much ridiculed, and was abandoned.

About 1803, Robert Fulton, the inventor of the steamboat, developed and built a considerably larger boat for the French Government. However, it was also propelled by hand power and due to its slow speed, was turned down as a failure by the Government. In 1863 the French again became interested in the submarine, and completed the largest boat built up to that time, having a displacement of nearly 500 tons. It was propelled by compressed air engines, but the capacity for compressed air was so small that it could remain submerged for only very short periods, and could obtain a speed of only about five knots. After considerable experimentation, the project was abandoned.

About this time J. P. Holland of the United States began his important work in the development of the submarine. He built several experimental boats, and in 1890 completed the first submarine to be accepted by the United States Navy Department. This vessel, called the "Holland", had gasoline engines for surface propulsion, and electrical motors, receiving power from storage batteries, for propulsion when submerged. It was the first boat for naval service thus equipped, and was quite successful. During the same period, European engineers had been attempting to use steam engines for submarine drive, but without much success.

Simon Lake took up the development of submarines in this country after Holland, and made great progress in the way of control and military efficiency. However, it has been only within the last 12 years that continued systematic and practical development of the submarine has been carried out. The combined efforts of naval authorities and experts and the engineering profession, have resulted in a rapid advance in the solution of the many problems encountered in the design and construction of the submarine.

One of the latest submarines in the United States Navy is shown in Fig. 1. This vessel has a displacement of 800 tons, and is designed for a speed of 15 knots on the surface, and 12 knots submerged. For the purpose of classification, the electrical equipment of a submarine may be grouped under the following heads:

FIG. 1—UNITED STATES SUBMARINE

1—Main propulsion, generating and power storage equipment and control.
2—Auxiliary motors and control.
3—Communication and signaling apparatus.
4—Lighting and heating equipment.

MAIN PROPULSION

The selection and design of the main propulsion machinery for a submarine involves problems and questions not encountered in the case of any other type of vessel. These result largely from the requirement that the boat operates satisfactorily and efficiently both when on the surface and when submerged—two widely differing conditions. It has been found during the later years of submarine development that, for the larger type of vessel now being built, the Diesel heavy oil engine is best adapted to meet the requirements for propulsion for surface operation. Up to the present time, the electric motor in conjunction with the storage battery has been the most successful machine for propelling the boat when submerged, and it bids fair to hold that position for some time to come.

The general arrangement of the propelling machin-

ery for the modern submarine is shown in Fig. 2. It will be noted that there are two main motors. Each has its own shaft, which is connected by heavy clutches to the engine shaft at one end, and to the propeller shaft at the other end. The clutches are so arranged that neither the thrust of the propeller nor that of the

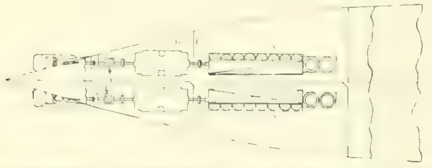


FIG. 2—GENERAL ARRANGEMENT OF THE PROPELLING MACHINERY
A—Engines; *B*—Motors; *C*—Clutches; *D*—Propellor thrust bearing; *E*—Bulkheads.

engine may be transmitted to the motor thrust bearing which, therefore, has to provide only for the thrust due to the weight of the motor rotor, shaft, and its clutch members when the boat is operating with its main axis at an angle with the horizontal, as when diving.

MAIN MOTORS

The limitations to the design of a submarine motor are probably closer and more rigid than in the case of any other marine application. It is necessary to obtain the maximum output with the minimum weight and size, as the space available in a hull where every inch has to be utilized, is of course limited. Then, too, the dimensions of the space available for the main motors are more or less fixed by the location of other apparatus, and these dimensions are usually such that special features have to be incorporated in the entire motor design.

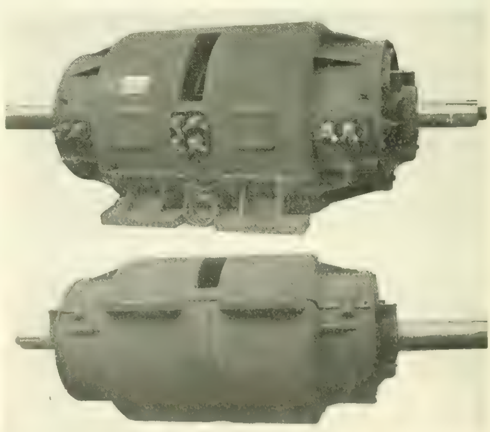
Special features in the design are necessary to meet the requirement for accessibility. Due to the particular location of the motor in the vessel, it is possible to reach only a small section of the frame for inspection. In this section it is necessary to provide handholes for inspection of the commutator and brushes. Means must also be provided for rotating the brush rigging so that all the brushes may be inspected from this point. The bearings also have to be designed for accessibility.

Not only must the motor be able to operate as such to propel the boat, but it must be capable of operating as a generator to charge the storage batteries and to furnish power to all the auxiliary electrical apparatus described later in this article.

For military reasons, the motors must operate as quietly as possible, which necessitates special features in the design to reduce noise due to commutation, magnetic hum, etc. They must be very efficient, since they receive power from the storage battery, so that the radius of action of the vessel submerged, depends directly upon their efficiency. It is desirable that the efficiency be as high as possible at loads obtained at all speeds within the range of motor speeds, because the boat may have to cruise at a speed corresponding to the full field speed of the motor for long periods, perhaps up to 48 hours, while patrolling. The motors must have specially designed bearings, both to prevent oil getting into the windings, and to take care of the end thrust of the motor rotor. All these requirements will serve to show that the submarine motor is necessarily of very special design.

A view of the inboard side of one of the latest type submarine motors, such as is used on the class of boats pictured in Fig. 1, is shown in Fig. 3, and the outboard side is shown in Fig. 4. This motor has a continuous rating of 600 hp at 260 r.p.m., 220 volts. It consists of two armatures mounted on a common shaft as shown in Fig. 5, which is carried in the common frame fitted with two separate field windings. This arrangement produces a rather long frame with small diameter, which best suits the space available in the boat. The double armature type motor also has some advantages over the single armature type in the way of control which will be pointed out later.

The motor is shunt wound with a light series winding to produce a drooping speed characteristic to provide for satisfactory division of load between the two armatures when operating in parallel. It is totally enclosed and arranged for forced ventilation, the air being furnished by a motor driven blower mounted directly above the main motor. The air outlet is shown at the center of the frame in Fig. 3, and the inlet in Fig. 4, Fig. 6 shows the channel shape sheet metal housing which directs the ingoing air into its proper path, and separates it from the outgoing air. This picture also shows the two field windings; the main poles are skewed in order to lessen the noise of operation. These photographs also show the special frame construction. The



FIGS. 3 and 4—INBOARD AND OUTBOARD SIDE OF LATEST TYPE OF SUBMARINE MOTOR

frame is split at an angle of 30 degrees from the horizontal to facilitate removal of the upper half. The feet are also arranged at the same angle, so that the frame will fit closely to the hull of the vessel. The bearings, carried in solid brackets, are of the sleeve type, oil and

waste lubricated, and similar in design to the type of bearing used in electric locomotive practice.

These motors have to be very rugged, as the actual service conditions are quite severe. They are in almost constant use. When cruising on the surface with the engines driving, the motor operates as a generator to

FIG. 5 DOUBLE ARMATURE MOTOR
Having a continuous rating of 600 hp at 260 r.p.m., 220 volts.

supply power to the auxiliaries, with the battery floating on the line. During submerged runs, they operate as motors to propel the boat, and when the boat is at rest on the surface, they are used to charge the batteries. They are also required to start the engines.

CONTROL

For starting the main motors, interlocked electromagnetic contactor switches, operated by a master controller, have been used most extensively. Speed variation is obtained by hand adjustment of the shunt field rheostats. Some of the latest class of boats are being equipped with electro-pneumatic contactor switches operated by a master controller, which also operates the adjusting mechanism of the field rheostats.

A switch group containing the pneumatically-operated contactors for the control of one motor is shown in Fig. 7, and Fig. 8 shows the group with the covers removed. This group contains 14 switches, which provide for cutting out the starting resistors in steps, for making series and parallel connections of the two armatures, and for reversing. These are standard switches such as are used in heavy electric railway locomotive control. The group, however, is longer than those used in locomotive practice, due to the large number of switches required. It is also inverted in position, the air valves and magnets being upon the upper side. This facilitates leading the main conductors from the motor, the group being mounted directly above it. The cylinders receive air from the submarine's compressed air supply through a reducing valve and control reservoir. Provision is made for manual operation of the switches in case the master controller circuits should be interrupted. This is done by means of a shaft located at the upper and front side of the group. This shaft carries cams which operate levers which depress the valve stems, admitting air into the cylinders, so that the switches are closed in the proper sequence for bringing the motor up to full parallel in either direction. The shaft is operated by a hand wheel mounted on the after end of the group.

Fig. 9 is a front view of the master controller by means of which both main motors are completely controlled throughout the entire speed range when motoring, or when generating. Each hand wheel gives individual control of one motor. In the lower part of the controller, are two large drums operated from the hand wheels by means of sprockets and chains. These drums make the proper connections of the control circuits to the valve magnets of the contactor switches for closing them in the proper sequence for starting the motors, and then connect shunt field resistors into circuit as the hand wheel is moved around from the "off" position, either ahead or astern. The hand wheel carries a dial which moves under a pointer, and indicates the speed notches, which are made pronounced by means of a star wheel and pawl mechanism. A series parallel drum is provided in the controller which can be set so that the motors can be started up with the armatures connected in series, or in parallel. This drum is mechanically interlocked with the hand wheels so that it cannot be moved except when the hand wheels are at the "off" position. Drums are also provided for cutting out of the circuit either armature of either motor, so that in case one armature should become disabled, the motor could still be operated with the other armature. These drums are operated by handles extending from the front side of the controller.

Each motor armature has an overload relay in its circuit, which interrupts the control circuits of the main switches when the current for which it is set is exceeded. The series parallel drum of the master controller provides for electrically resetting the relay after the hand wheels are returned to the "off" position.

The switch groups and overload relays are mounted in the motor room, while the master controller is lo-

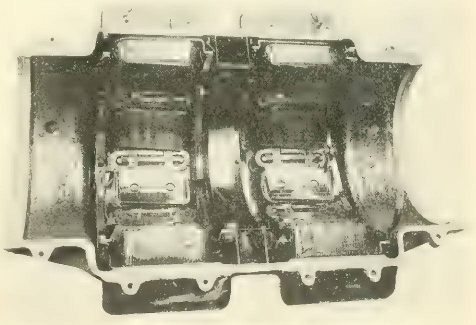


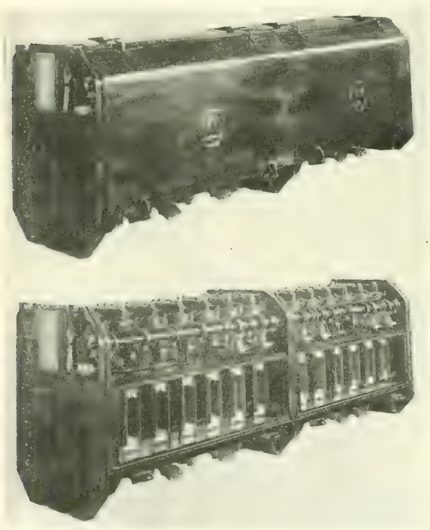
FIG. 6—MOTOR FRAME
Showing field coils and channel shape sheet metal housing which keeps the ingoing and outgoing air separated.

cated in the central operating compartment at the center of the vessel. Near the master controller, is mounted the main switchboard carrying the necessary meters for the motors, batteries, and auxiliary circuits, circuit breakers and switches for the main auxiliary circuits, and the main circuit breakers in the battery

lines which also serve for making series and parallel connections of the battery sections

STORAGE BATTERIES

The storage battery which is most generally adopted for submarine service is of the lead battery iron-clad type. The battery is usually arranged in two groups of 60 cells each, with the three main circuit breakers arranged for connecting the two halves of the whole either in series or parallel, thus furnishing either half or full battery voltage. This arrangement in combination with the double armature motors and scheme of control provides a wide range of economical running speeds of the motors. Thus for high speeds, the battery sections would be connected in series, and the armatures in parallel, giving full battery voltage on each armature. For medium speeds, half battery voltage would be applied to each armature, either by using parallel connections of both armatures and battery sections, or by series connections of battery sections and of armatures. For the lowest speeds, the battery sections would be connected in parallel and the armatures in series, giving one fourth the voltage on each armature. The full range of shunt field steps is available for each of these conditions.



FIGS. 7 and 8—SWITCH GROUP
Containing the pneumatically-operated contactors for the control of one motor

The battery cells for submarine service have to be very ruggedly built. Some idea of their size may be gained from the fact that a single cell, complete with electrolyte, weighs about 2400 pounds. Thus a complete battery of 120 cells weighs about 150 tons.

AUXILIARY MOTORS AND CONTROL

A considerable number of auxiliary motors is required on a submarine for operation of pumps, steering gear, etc. In Table I is given a list of auxiliary motor applications that would be made on a vessel such as shown in Fig. 1. The ratings given are only approximate, and typical for this class of submarine. They will, of course, vary somewhat with different boat designs and sizes. From a summary of this table, it will be noted that a total of about 180 hp of auxiliary motors is required for one submarine. Some of these motors are water-tight, some semi-enclosed, the others open, depending upon the location in the submarine and the application. It is necessary that all motors be as small and light as possible.

For the control of constant speed motors, such as pump motors, enclosed contactor panels controlled by water-tight push button master switches are used. This allows for installing the panels in out of the way places

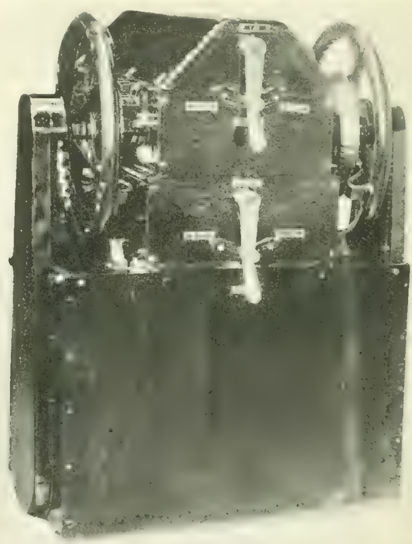


FIG. 9—MASTER CONTROLLER

where space is available. In the case of adjustable speed motors, such as fan motors, hand operated panel type controllers enclosed in sheet metal boxes are generally used.

The steering and diving gears are equipped for hand operation in case the electrical equipment or the voltage fails. In this connection, electric clutches are provided which immediately throw the hand operating mechanism into gear upon the failure of voltage. They also have limit switches which stop the motor when the limit of travel of the rudder or diving planes is reached. This auxiliary control equipment must have the highest degree of reliability, as the safety of the boat and the lives of the crew are directly dependent upon its operation. Especially is this true of the steering and diving gear apparatus.

TABLE I—AUXILIARY MOTOR EQUIPMENT OF A TYPICAL MODERN U. S. SUBMARINE

No. per boat	Application	Hp each
2	Air compressor and ballast pump	45
2	Engine circulating water pump	10
1	Anchor windlass	10
1	Steering gear	7.5
1	Oscillator generator	7.5
1	Adjusting pump	7.5
2	Main motor ventilating fan	5
1	Stern diving rudder	4
1	Bow diving rudder	3
3	Periscope hoist	3
1	Wireless generator	3
1	Engine lathe	3
1	Radio mast hoist	1.5
1	Bilge pump	1
2	Lubricating oil pump	1
1	Fuel oil pump	1
1	Sounding machine	½
1	Drill press	¼
1	Grinder	¼
1	Refrigerating machine	¼
7	Hull and battery ventilating fan	¼
3	Hull ventilating fan	⅛

COMMUNICATION AND SIGNALING

Electrical circuits and devices play a very important part in the communication, signaling and controlling systems of the modern submarine. An engine-motor telegraph indicating system is used for signaling the motor or engine operator from the conning tower or bridge. An electric gong rings at the same time that the signal appears on the telegraph indicator. An extensive electric call-bell system is used as well as general alarm gongs. The firing of the torpedoes is accomplished from the bridge or central operating compartment by means of firing keys and electric circuits controlling magnets operating the air valves which connect the torpedo tubes to the compressed air tanks. A gyro-compass is, of course, necessary, and the gyroscope is driven by a small electric motor. This is an induction motor so that a small motor generator set is required to supply its power.

For outside signaling, a complete radio equipment of medium capacity is supplied. Each boat is also equipped with a submarine signal which consists of an electrical device for producing vibrations for transmittal through the water. A corresponding telephonic receiving device is used to pick up vibrations from the water for the detection of the approach of ships.

LIGHTING AND HEATING

The submarine is thoroughly lighted with standard lamps, enclosed by heavy glass globes for protection. All lamps on the starboard side of the boat are connected to one feeder, while those on the port side are connected to another, so that the lighting of each side of the boat is separately controlled. Dimmer rheostats are connected in to protect the lamps from the excessive voltages occuring when the batteries are being charged.

For heating, electrical resistor radiators are installed in necessary parts of the boat. An electric range and electric water heaters are installed in the galley.

The apparatus enumerated in the preceding pages constitutes the complete electrical equipment of a typical submarine of the present day. For future development of submarines, indications point toward a considerable increase in size and power. While this will, of course, increase the size and rating of the electrical apparatus, it will not materially change the outline of the required number and kind of appliances.

Proposed Changes in the American Patent System

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THE foundation of many of the great American industrial organizations was laid in patents and it is largely due to the spur and stimulus of patents and patent protection that the United States has acquired its present position of pre-eminence in the industrial world.

With the reorganization of world affairs, attendant upon the closing of the great war, industrial competition between the different nations promises to be more active and more bitter than ever before and, under these conditions, it behooves American industry to devise and to develop every possible means for increasing the efficiency of labor and for the production of goods at lower costs.

Careful thought should be given to the American patent system to see that it is, in every way, as well adapted as may be possible for the important function it is to perform in stimulating invention and mechanical development in the coming years.

Bearing these conditions in mind, the National Research Counsel recently appointed a committee of men having exceptionally high qualifications to investigate and report upon the patent system, with a view to ascertaining its more pronounced defects, and to formulate methods and means for curing them and to further propose such innovations as may be demanded by the developments of our national life. This committee was constituted as follows:—Dr. William F. Durand, Chairman; Drs. Leo H. Bækeland and M. I. Pupin, scientists and inventors; Drs. R. A. Millikan and S. W. Stratton, scientists; Dr. Reid Hunt, physician; and Messrs. Frederick P. Fish, Thomas Ewing and Edwin

J. Prindle, patent lawyers. On the departure of Dr. Durand for Europe, Dr. Bækeland was appointed Acting Chairman of the Committee.

After careful investigation and mature deliberation, the committee made four definite recommendations which it believed would increase the effectiveness and usefulness of the Patent Office and of the patent system, and these recommendations were embodied in bills introduced into Congress. The four committee recommendations are as follows.

A SINGLE COURT OF PATENT APPEALS

At present, the United States is divided into nine judicial circuits and each circuit has its own Circuit Court of Appeals, which is the court of last resort in patent suits except under certain unusual conditions, discussion of which is not pertinent here. The existence of these nine courts, having concurrent and coextensive jurisdiction, leads to great confusion, as it is practically impossible for different bodies of men, having different training and viewpoints, to construe the same facts in the same way or to apply the same law in the same manner. Thus, a patent may be held valid in one circuit and invalid in another, with attendant doubt and confusion as to the true status of the rights afforded thereby.

It is proposed to constitute a single Court of Patent Appeals to sit in Washington, the Court embodying seven members, one a Chief Justice to sit for life and the other six to be selected from among the Federal Judges of the country by the Chief Justice of the Supreme Court of the United States.

A court of this character would do much to crystalize the patent law and would pave a way, by a line of leading decisions, whereby many questions that at present vex and harass those interested in patents would be rendered capable of solution in a prompt and effective manner.

THE PATENT OFFICE A SEPARATE INSTITUTION AND INDEPENDENT OF THE DEPARTMENT OF THE INTERIOR

At present, the Patent Office is a branch of the Interior Department, although it has nothing in common with any other branch of this Department. The Secretary of the Interior has appellate jurisdiction over all the other branches of the Department of the Interior but exercises only a slight supervisory authority over the Patent Office.

All appropriations, etc. for the Patent Office are subject to examination and criticism in conjunction with appropriations for other branches of the Interior Department, such, for example, as the Pension and Land Offices. Obviously, a request or a need for a large sum of money in the Pension Office should have no effect on the appropriation for the Patent Office but, so long as these offices are bureaus of the same Department, their appropriations are subject to competitive examination and, consequently, the Patent Office does not receive the consideration that it merits.

It is proposed to conduct the Patent Office as a distinct government bureau so that its appropriations, etc. may be subject to independent examination and be given consideration in accordance with their merits.

INCREASES IN SALARIES OF THE PATENT OFFICE

The salaries of the principal examiners in the Patent Office have increased only ten percent since 1848, when they were approximately the same as those of members of Congress. During the past seventy years, the compensation for technical service, in almost all lines, has been increased very largely but the Patent Office examiner receives practically the same remuneration for work of a highly technical character as was paid seventy years ago, although the compensation of Congressmen has tripled in the meantime.

Although a principal examiner must necessarily have had a liberal technical education in order to have acquired the position he holds, his salary is only $2700 per year which is not only insufficient to enable him to provide a college education for his sons but is hardly more than the wages of a day laborer, under existing economic conditions. Such compensation is obviously and grossly inadequate.

Largely because of inadequate compensation, an extremely rapid turn-over of the force within the Patent Office is an ever present condition, 25% of the examiners and assistant examiners having resigned within the past three years. It necessarily follows that the consideration and examination given to applications falls far short of what would be possible with a force of adequately paid examiners of long experience.

It is proposed to increase the salaries of the examining corps, in order that they may conform, with some degree of approximation, to the present salaries paid to outsiders having similar technical equipment and engaged in work of corresponding technical character.

COMPENSATION FOR INFRINGEMENT OF PATENTS

At the present time, if an infringer of a patent is brought to Court, an injunction may be obtained barring him from further infringement but it is extremely difficult to secure adequate compensation for past infringement. Particularly is this true where the infringing structure has constituted only a part of the article as sold and wherein its effect upon the salability was therefore more or less indefinite. It is proposed that the Court, on due proceedings had, may adjudge and decree to the owner of a patent payment of a reasonable royalty or other form of general damages as compensation for past infringement, a power which the courts are now extremely loathe to exercise, in the absence of specific legal authority.

The above suggestions have been made by a highly competent committee of men outside the Patent Office, after long and careful consideration, and are believed to merit the careful thought of everyone interested in the American Patent System and to justify the exercise of every reasonable effort to induce Congress to embody them in legislative enactments.

Essentials of Transformer Practice-XXIV

Polarity

E. G. Reed

If two transformers are connected in parallel and a large exchange current results, the position of either the primary or secondary terminals of one of them must be interchanged. This will reverse the time-phase relation of the secondary voltage of that particular unit, and the condition for parallel operation will be established. In connecting transformers in parallel, if the relative direction of the primary and secondary windings around the magnetic circuit, and the position of the leads issuing from the case are the same on the two units, similarly located leads should be connected together. Transformers which may be connected for parallel operation with similarly located leads joined, are said to have the same polarity. If leads which are not similarly located are required to be connected together in order to obtain parallel operation, the transformers are said to have opposite polarity. Transformers of a given type have the same polarity, a standard polarity being necessary so that the transformers may be connected always in the same manner when they are to be operated in parallel. Transformers of the same class, for example distribution transformers, usually have the same polarity.

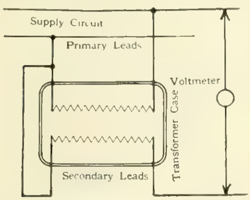

FIG. 1—CONNECTIONS FOR DETERMINING THE POLARITY OF A SINGLE-PHASE TRANSFORMER

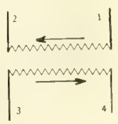

FIG. 2—METHOD OF MARKING THE LEADS TO INDICATE POLARITY

POLARITY OF SINGLE-PHASE TRANSFORMERS

If a transformer be connected as shown in Fig. 1, the value indicated by the voltmeter will be the sum or the difference of the voltages of the supply and load circuits. Whether the voltmeter will indicate the numerical sum or difference of these voltages, will depend upon the relative directions of the two windings around the magnetic circuit, and on the way the leads are brought out. Two transformers have the same polarity if the voltages indicated by a voltmeter connected on first one and then the other, as shown in Fig. 1, are the sum of the supply and load circuits for both units or, are in both cases, the difference of these voltages.

In order that the polarity of transformers shall be at once apparent so that parallel connections will be expedited, it is customary to mark the leads so that the phase relation of the voltages in the primary and secondary windings will be indicated. For example, if the leads are marked as shown in Fig. 2, the convention is to indicate that if the winding whose leads are marked 1-2 be excited by a voltage whose phase relation is indicated by the arrow pointing from *1* to *2*, the phase relation of the voltage in the secondary winding will be indicated by the arrow pointing from *3* to *4*. In other words, the two voltages are 180 degrees apart in time phase relation, and consequently when leads *2* and *3* are connected together, the voltage between leads *1* and *4* would be the sum of the impressed and delivered voltages or the polarity would be additive. To operate transformers thus marked in parallel, as far as the matter of polarity is concerned, it is only necessary to connect similarly marked leads together.

The above, while having a practical value, is a rather superficial discussion of the subject of polarity as is evidenced by the following. Fig. 3 indicates the coils shown in Fig. 1 and 2, wound on the magnetic circuit in a continuous spiral, so as to give an additive polarity when they are connected as shown in Fig. 1. The voltage between *4* and *1* is not actually the sum of that impressed on the primary winding and that induced in the secondary winding, but is the induced voltage in the two coils connected together and considered as one winding. The arrows on the leads indicate the instantaneous directions of the currents in the windings which would result if *1* and *4* were connected together. If the coil *3-4* had been wound around the magnetic circuit in the direction opposite to that of *1-2*, the induced voltages in the two coils would have opposed each other and the polarity of the transformer would have been subtractive.

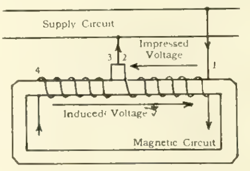

FIG. 3—RELATIVE DIRECTION OF THE IMPRESSED AND INDUCED VOLTAGES

In the windings of a single-phase transformer whose polarity is additive when the leads are connected as indicated in Fig. 1.

POLARITY OF THREE-PHASE TRANSFORMERS

It has been shown that, if two similar single-phase transformers be connected in parallel, and a condition results which is not operative, it is only necessary to

reverse either the primary or secondary connections of one transformer and the difficulty will disappear. With three-phase transformers the problem is not so simple, and the different methods by which the coils are wound or connected may result in conditions in which it is not possible to parallel one transformer with another by interchange of the leads on the outside of the case.* This will be seen by comparing the several connections with the corresponding vector diagram of voltages.

Let the direction of winding the coils, for example, be indicated by Fig. 4, which shows that if the current enters by lead *A*, it goes left handedly around the coil, and if by lead *a*, it goes around right handedly. The change from left handed to right handed circulation of the current around the magnetic circuit could also be

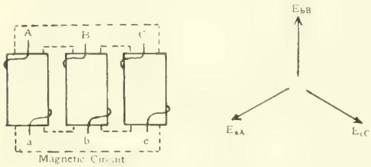

FIG. 4—THE ASSUMED DIRECTIONS OF THE VOLTAGES IN THE THREE COILS

When a three phase flux exists in the magnetic circuit.

changed by actually changing the direction of winding the coil. Assume that a three-phase flux exists in the magnetic circuit and let the voltages of the three coils be represented by the arrows in Fig. 4. If these three coils are connected in the several ways shown in Fig. 5, the three-phase voltages resulting are shown by the vector diagrams. The left-handed star connection, for example, is so called because current entering on lead *A* passes left handedly around the coil. Fig. 5 shows the four different connections, which give voltages differing in phase relation:—

The primary windings of a given transformer may be connected to give voltages shown in *a, b, c,* or *d,* and the secondaries may be connected in a similar manner. This makes possible 16 different connections on one transformer, and the problem is to determine how many of these combinations will allow one transformer to be paralleled with another transformer having the same possible connections. When comparing a certain connection on the primary with one on the secondary, the phase relation of the voltages as shown by *a, b, c, d,* must be rotated 180 degrees to represent the true secondary condition. The reason for this being that with similar windings on primary and secondary, the secondary voltage of a transformer is 180 degrees out of phase from that impressed on the primary side. The following table gives the angular displacement between the primary impressed and secondary delivered voltages for all of the possible combinations, Fig. 5.

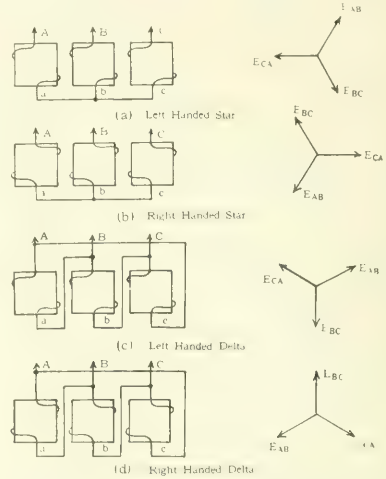

FIG. 5—THE PHASE RELATION OF THE THREE-PHASE VOLTAGES

Resulting from the several connections shown.

Combinations Primary	Combinations Secondary	Angular. Displacement. Degrees.
a	a	180
a	b	0
a	c	30 advance
a	d	30 retardation
b	a	0
b	b	180
b	c	30 retardation
b	d	30 advance
c	a	30 retardation
c	b	30 advance
c	c	180
c	d	0
d	a	30 advance
d	b	30 retardation
d	c	0
d	d	180

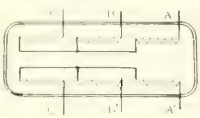

FIG. 6—MARKING OF LEADS ON A STAR-STAR CONNECTED THREE-PHASE TRANSFORMER

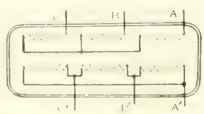

FIG. 7—MARKINGS OF LEADS ON A STAR-DELTA CONNECTED THREE-PHASE TRANSFORMER

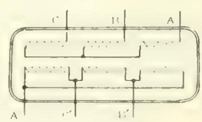

FIG. 8—BRINGING THE LEAD A′ OF A STAR-DELTA CONNECTION OUT AT A DIFFERENT POSITION RELATIVE TO LEADS B′, C′

These combinations will operate in parallel in which the primary and secondary voltages are out of time-phase by the same amount, except those cases where the displacement is in advance in one case and a retardation in the other. For example *a-c* and *a-d,*

*See article on "Polarity of Transformers for Parallel Operation" by W. M. McConahey in the JOURNAL for July, 1912, p. 613; and on "Polarity of Transformers" by W. M. Dann, in the JOURNAL for July, 1916, p. 350.

while each have an angular displacement of 30 degrees, will not parallel with each other because the secondary voltages are out of phase by 60 degrees. From an inspection of this table it is evident that the following combination will parallel, as far as polarity is concerned.

a—a with b—b, c—c, and d—d.... 180° angular displacement
a—b with b—a, c—d, and d—c.... 0° angular displacement
a—c with b—d, c—b, and d—a.... 30° angular displacement (advance)
a—d with b—c, c—a, and d—b.... 30° angular displacement (retardation)

When it has been determined that two three-phase transformers have the same angular displacement of the secondary voltage compared to that impressed on the primary side and therefore can be operated in parallel, it remains to be determined which leads should be connected together on both the primary and secondary sides. In order to expedite this connection of leads it is customary to mark them so as to indicate the phase sequence of their voltages. If, for example, the leads issuing from the high voltage side of a transformer are marked *A*, *B*, *C*, and the low voltage leads are marked *A′*, *B′*, *C′*, the letters can be so placed on the leads as to indicate the phase sequence of the voltages as shown in Fig. 6. In connecting the two transformers in parallel, like-lettered leads are connected together on both the high voltage and low voltage sides. The phase sequence of the leads may be traced out in several ways but the most obvious one is by the use of Fig. 5, which indicates that similarly located leads should have the same letter on all transformers. For example, if the high voltage leads are marked *A*, *B*, *C*, as shown in Fig. 7, the low voltage leads should be marked as indicated. Had the lead marked *A′* on the low voltage side been brought out the other side of the B′, C′ leads, it should be so marked as shown in Fig. 8.

The Flow of Power in Electrical Machines

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In the following article it is shown that the usual concept of power flow in conducting wires does not correspond to any physical fact, and the necessity is developed for believing in a power flow through the insulating space around the wires. The Poynting vector which gives this power flow is defined and its properties explained. By means of it the power flow in the reactor, transformer, direct-current generator, alternator, synchronous condenser and induction motor is pictured.

In THE mental picture which most engineers have of the electrical machines with which they are familiar, the wires which carry current serve at the same time to carry electric energy to the places where it is transferred into mechanical or other form. Thus they think of the power flow as occurring in the conducting wires. They have heard of another conception, namely that the power flow really takes place not in the conductor, but in the space surrounding the conductor, but few have really understood this conception.

This supposed power flow in the conductor is taken to be given quantitatively by the product of the potential and the current at any cross-section of the conductor. This gives correct results for certain simple circuits. For example, assume a heating coil in a bag, with the two terminals, *a*, *b*, protruding. Let us bring the terminal *a* to potential V_a and the terminal *b* to potential V_b so that a current *i* flows in at *a*. Then entering the bag at *a* is the current *i* at potential V_a, so that supposedly we have the power $V_a i$ entering at terminal *a*. Similarly, at terminal *b* we have the power $V_b \times (-i) = V_b i$ entering the bag. Thus the total power entering the bag is $V_a i - V_b i = (V_a - V_b) i$. Now this actually equals the Joulian heat developed, as application of Ohm's and Joule's laws would show, and thus seems to be a verification of the theory of power flow in the conductor.

However, even if there is an electric power flow in the conductors, there must be some other mode of transfer of electrical energy. For example; assume two coils inductively coupled. Across the terminals of one put a resistor. Put a bag around the other, and apply an alternating potential difference to the terminals *a*, *b* which protrude. Then just as before, the power flow into the bag at the terminals *a*, *b* is $(V_a - V_b)\, i$. Now there is no transformation within the bag of electrical energy into other forms. The transformation into heat takes place in the resistor outside the bag. Hence the power flow into the bag at the terminals *a*, *b*, cannot be the whole story. There must be an equivalent power flow out of the bag in some other way.

When we come to examine conditions inside the conductor, we fail to find any physical evidence of this supposed power flow, *Vi*. There seems to be no relation between conditions inside the wire, and the power transmitted. Consider, for example, a transmission line with return wire carrying a direct current *i*. Within the wire we have both an electric and magnetic field. The electric field is that which is necessary by Ohm's law to cause the current *i* to flow. If the wire is of constant cross-section and resistance, and if the current is uniformly distributed over the cross-section, then the electric field in the wire will be a uniform field with the lines of force parallel to the axis of the wire, and the magnitude of the electric force will be equal to the resistance *r* of a unit length of the wire, multiplied into the current *i*. This field is shown in Fig. 1 (*a*). The vertical lines represent equipotential surfaces, and the horizontal arrows the lines of force.

By the electric force at any point is meant the mechanical force which would be exerted upon a unit electric charge placed at that point. In the case of the

electric field produced by static charges, the electric force is the gradient of the electric potential. Fields of electric force may, however, be produced otherwise than by static charges; such fields of electric force appear where magnetic flux changes. This is explained more fully in the section dealing with the reactance coil.

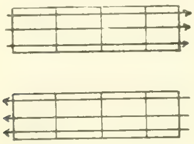


FIG. 1(a)

FIG. 1(b)

(a) Electric field in wires.
(b) Magnetic field in wires.

Electric fields produced by this last means consist of lines of force forming closed loops, and have no potential. When a conductor lies in such a field, charges automatically appear on the surface, in such a way as to make the electric field inside the conductor correspond to the current inside the conductor according to Ohm's law. Because of these surface charges, the electric field inside a conductor is usually very different from the field outside. Lines of electric force coming from outside, terminate in these surface charges and do not pass on into the conductor. The electric field due to these surface charges alone has a potential, and it is this potential which is commonly used in electrical engineering.

The magnetic field inside the conductors, if the cross-sections are circular, and the wires are not too near together, will consist of lines of force which are concentric circles. The intensity of the magnetic force is easily found. Letting H_r be the intensity at a distance r from the center of a cross-section, by putting the magnetomotive force around the concentric circle of radius r equal to $4\pi \div 10$ times the current enclosed,—

$$2\pi r H_r = \frac{\pi r^2}{\pi a^2} i \frac{4\pi}{10} \text{ or } H_r = \frac{2 i r}{10 a^2},$$

where a is the radius of the cross-section of the wire.

Now take this same transmission line and, keeping the current the same, double the voltage. Then the power transmitted must be twice that transmitted with the lower voltage. Now how are conditions changed inside the wires with this increased power flow? The

FIG. 2

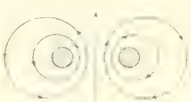


FIG. 3

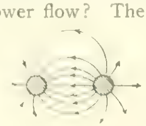
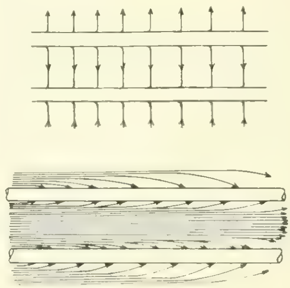


FIG. 4

current is, of course, the same. Now the electric field inside the wire is entirely determined by the current alone. That is, the electric force must have that value called for by Ohm's law to give the current i. Hence, the electric field inside the wires is exactly the same with this doubled power flow as before. Also, the magnetic field inside the wires depends only on the current and is, therefore, just the same as before, in spite of the doubled power flow. Thus current, electric field, magnetic field are all unchanged inside the wires. If we imagine a being confined inside the wire, he would find absolutely no difference in the conditions of his surroundings, no matter how the power flow would be changed, if only the current were kept constant.

This examination of the interior state of wires makes it seem probable that the flow of energy does not take place inside the wires. We are, therefore, compelled to say that the flow takes place in the medium outside of the wires. Let us examine the medium exterior to the transmission line conductors considered above, under the conditions of constant current and change of voltage with a consequent change of power delivery. There will be an electric and a magnetic field in this medium. Neglecting for the moment the resistance of the wires, the electric field consists of lines of force which are circular, and terminate perpendicularly on the surfaces of the conductors. (Fig. 2). The magnetic field will be indicated by closed circular lines of force enclosing the wires. (Fig. 3).



FIGS. 5 and 6

Now suppose the voltage be doubled but the current be kept unchanged. Then the magnetic field in the exterior medium will be unaffected, but the electric field will be doubled in strength. (Fig. 4). Thus the state of the external medium is changed when the power flow is changed. Assuming then that the power flow does take place in the medium, it would be natural to suppose that it is most concentrated where the electric and magnetic fields are strongest. Also, in the example here discussed the total power transmitted is proportional to the product of the potential difference between the conductors and the current. Now the electric field strength at any point is proportional to this potential difference, and the magnetic field strength is proportional to the current. This suggests that the power flow at any point is proportional to the product of the electric and magnetic field strengths at the point. The example here discussed also suggests that the direction of power flow at any point is perpendicular to both the electric and magnetic force at the point.

Poynting, an English physicist, first proposed that the following vector be taken to represent the power

flow at any point. The direction of the vector is perpendicular to the directions of the electric and magnetic vectors at the point considered, and is related to the electric and magnetic force like the middle finger of the right hand is related to thumb and forefinger in the usual convention; the magnitude of this vector is:—

$$\frac{4\pi}{c} E\,H \sin\theta$$

Where, E and H are the intensities of the electric and magnetic force respectively, and θ is the angle between them. The factor of proportionality, $\frac{4\pi}{c}$ is for absolute units, c being the velocity of light. This vector is called the Poynting vector and is extensively used by workers in theoretical electromagnetism.

Poynting showed that if a portion of space, including any electrical apparatus, be enclosed by a surface, say by a bag, and if the power flow inward through the various parts of the surface be calculated by means of the Poynting vector and totaled for the whole surface, the result will give the rate at which the electromagnetic energy is increasing within the surface plus the rate at which electromagnetic energy is being changed into other forms within the surface. Then, whether or not the Poynting vector does represent the true power flow at a point, we will always be led to correct results when using it.

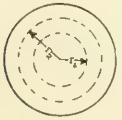


FIG. 7

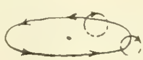


FIG. 8

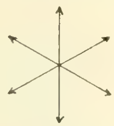


FIG. 9

Turning now to the transmission line, it can be seen how the Poynting vector is disposed there. Assuming that the wires have resistance, it is seen that the electric field will be modified, as there must be a potential gradient parallel to the wires, so that in the neighborhood of the conductors the electric force will have a component parallel to the conductors. Also the electric force must decrease as one progresses along the wire. Hence from Fig. 2 is obtained the diagram of the electric field shown in Fig. 5. The magnetic field is as shown in Fig. 3. Combining the two fields to get the Poynting vector we get Fig. 6.

Here we see the lines of power flow dense at one end of the transmission line, but thinning out toward the load end, the lost lines running into the wires. Let us see what becomes of these lines inside the wires. The internal electric and magnetic fields are shown in Fig. 1. We see readily that the Poynting vectors point radially inward toward the axis of the wires. The intensity of the Poynting vector at a point distant r from the axis is proportional to,—

$$E \times H = E \times \frac{4\pi i}{10\,a^2} r \text{ or is proportional to } r = kr$$

Let us calculate the total power flowing into a cylindrical shell, of inner radius r_1, and of outer radius r_2, and one unit in length (Fig. 7). The Poynting vector on the outer surface has the value kr_2. The outer surface area is $2\pi r_2$. Hence the power flowing in through the outer surface is $2\pi k r_2^2$. Similarly, the power flowing out of the shell inwards from the inner surface is $2\pi k r_1^2$. The total power consumed in the cylindrical shell is $2\pi k (r_2^2 - r_1^2)$. The volume of the shell is $\pi (r_2^2 - r_1^2)$. Hence the power consumption per unit volume is $\frac{2\pi k (r_2^2 - r_1^2)}{\pi (r_2^2 - r_1^2)} = 2k$. This consumed power appears as Joulian heat. Thus the power which flows into the conductor from the medium is dissipated uniformly over the volume of the conductor as heat. The medium transmits the power. The wires dissipate whatever power flows into them. The function of the wires is not to carry the power, but to direct it, since the charges on the surface of the wires cause the lines of electric force to be perpendicular to the wire, and the current in the wire produces a magnetic field whose lines of force embrace the conductors; thus these two fields combine to give a flow of power parallel to the wires in the surrounding medium.

Consider now the following simple electrical system which offers some interesting points. Assume a wire forming a closed circular loop and carrying current. The form of the magnetic field which it produces is well known. (Fig. 8). Suppose the wire has so small

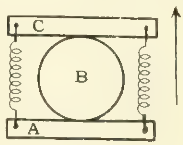


FIG. 10

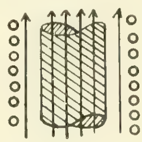


FIG. 11

a resistance that the electric field for maintaining this current may be neglected. Now take a unit positive electric charge, whose radial electric field is well known (Fig. 9) and place it at the center of the circular loop of wire. The whole electromagnetic field is now symmetrical about the axis of the circular loop. The lines of electric force and the lines of magnetic force lie in planes through this axis. Hence the Poynting vector at all points is perpendicular to these planes, and therefore, the lines of power flow are closed circles whose centers are on the axis. Furthermore, from symmetry, the Poynting vector is of constant intensity all along any circle of power flow. Thus although here there are no changes of energy distribution taking place, still the concept of the Poynting vector leads us to say that the energy is circulating round in closed loops.

The following mechanical example may make these ideas clearer. Consider a body made up of three parts, A, B, C. (Fig. 10) with the parts A, C held together with B between, by springs under tension. Suppose the whole to be moving with uniform velocity in the direction shown by the arrow. Then A, B and C each have definite constant amounts of kinetic energy. Now in mechanics when a force acts upon a moving body, we say that energy enters that body if the direction of the force is of the same sense as the velocity,

and leaves the body if the direction of the force is of the opposite sense as the velocity. The rate at which energy is entering or leaving the body is taken as equal to the product of the force and velocity. Correct results are obtained by these assumptions. Now let us apply this to the bodies *A*, *B*, *C*. Consider the reaction between *A* and *B*. The force on *A* is opposite in direction to the common velocity and hence energy is being removed from *A* by the reaction force between *A* and *B*. But the reaction of *A* on *B* is in the direction of motion of the bodies. Hence this force of reaction is doing work on *B* or supplying it with energy. Thus by means of the reaction force, energy is passing from *A* into *B*. Now consider the reaction between *B* and *C*. Here, evidently, we must consider the force of reaction as removing energy from *B* and supplying an equal amount to *C*. Lastly, the springs, pulling back on *C* and forward on *A* remove energy from *C* and supply it to *A*. Thus the principles of mechanics lead us to say that energy is flowing from *A* into *B*, from *B* into *C*, and from *C* through the springs back into *A*. The similarity between this and the preceding electrical example is clear.

The system of forces consisting of the reactions between the bodies and the tensions of the springs are such as to produce a local circulation of energy without any energy leaving or entering the body. By changing the tension of the springs, the magnitude of this local energy flow can be changed arbitrarily. We can superpose upon this local circulation of energy, another flow of energy through the system, if we suppose an external driving force acting on *A*, and an external resisting force at *C*. Then power is entering the whole body at *A*, and is being delivered out at *C*. The actual distribution of this power flow through the body depends on the amount of circulating energy flow produced by the tension of the springs, which is superposed on the direct flow of energy through the system. The local circulation of energy is without influence on the total energy entering and leaving the body. If we were interested only in the passage of energy through the body, we could neglect any local circulation of power in the body, even though strict application of mechanical principles would require us to consider it.

This is precisely what is done in the electrical examples here considered. In general, the electric and magnetic fields in electrical machines are of great complexity, and it is very difficult to obtain a complete picture of the Poynting vector and power flow. We shall consider the electric and magnetic fields in parts, that is, we shall consider separately the magnetic fields which different circuits would produce alone and the electric fields which different distributions of charges and different alternating magnetic fields produce. It is shown in Appendix I that it is legitimate to obtain the Poynting vector for the whole electromagnetic field by adding together the Poynting vectors given by taking each component electric field together with each component magnetic field. Certain of these component electric fields, together with certain of the component magnetic fields will give Poynting vectors which correspond to merely local circulation of power in the dielectric medium. This local energy flow will be neglected in the problems here considered, and the problems thereby much simplified.

The example given above of an electric charge with a current loop is typical of a type of electromagnetic field which produces only local circulation of energy in the dielectric medium. Given an electric field produced by maintaining certain conductors or different parts of the same conductors at different potentials; given a magnetic field produced by currents flowing in other conductors; then this electric field, taken together with this magnetic field, gives a Poynting vector which corresponds to only a local energy circulation in the dielectric medium. This is proven in Appendix II.

IRON CORED REACTANCE

Assume a long cylinder of iron, with a solenoid wound uniformly around it. For simplicity in mapping the magnetic field, suppose that no eddy currents exist in the iron, or in other words, that it is nonconducting. The magnetic field inside the solenoid will be practically uniform and parallel to the axis of the solenoid,

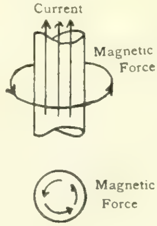


FIG. 12

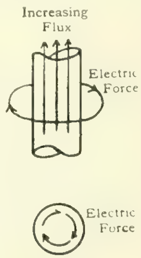


FIG. 13

(Fig. 11). Outside the solenoid the magnetic field is very small. It should be remembered that in the Poynting vector it is the magnetic force, that is the magnetomotive force per cm. which enters and not the magnetic flux density. The electric field we shall consider in two parts, one produced by the alternating flux, and the other by the charges which collect on the wires of the solenoid.

The law by which a varying magnetic flux produces an electric field is very similar to the law by which a current produces a magnetic field. In the latter case, the magnetomotive force, or the integral of the magnetic force around any closed loop in space is proportional to the current enclosed by the loop. In the former case the electromotive force or the integral of the electric force around any closed loop is proportional to the rate of change of the flux enclosed. If the flux along any line increases, there are produced closed lines of electric force surrounding that line. Figs. 12 and 13 show the fields produced by a current in a cylinder, and changing flux in a cylinder. The exact correspondence between

the changing magnetic field in Fig. 12 and the electric field in Fig. 13, stands out.

Now consider first the power flow inside the magnetic core. Compare conditions here with the interior of the wire considered in connection with Fig. 7. Here the magnetic field is uniform and parallel to the axis of the cylinder, and there the electric field was uniform and parallel to the axis. Here the electric field is of exactly the same character as the magnetic field there was. Hence the Poynting vector here must be similarly disposed, as the Poynting vector there, since only the product of the electric force and magnetic force appears in the Poynting vector. Thus energy enters the core from the outside, distributing itself uniformly over the volume of the core. This, of course, is the magnetic energy of the core. Since the magnetic field and electric fields are alternating and in time quadrature, the Poynting vector will alternate with double frequency as magnetic energy flows into and out of the core.

Outside the core the magnetic field is also constant until near the turns of the solenoid. There the lines of magnetic force bend and become closed curves around and in the wires. (Fig. 14). Combining this magnetic field with the electric field produced by the alternating flux, gives the Poynting vector disposed as

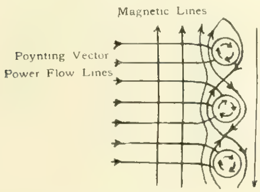


FIG. 14

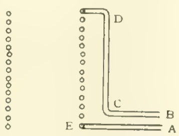


FIG. 15

the horizontal arrows in Fig. 14 show. Thus power flows back and forth from the core across the intervening space into the solenoid conductors.

Now examine the power flow corresponding to this same magnetic field and the electric field produced by the charges which collect on the turns of the solenoid. Suppose that the conductors have a negligibly small resistance. Then since very large currents do not flow, the electric force inside the conductors must be very nearly zero. That is, the charges which collect on the surfaces of the conductors are such as to reduce the electric field within the conductors to nearly zero; that is, the field produced by the charges is very nearly equal and opposite inside the conductors to the field produced by the alternating flux. An electric field produced by a varying flux does not in general have a potential (that is a scalar function whose gradient is the electric field), but a field produced by electric charges always does (except for high frequencies). We can trace the change in electric potential along the conductors of the field produced by the charges very readily, for the difference of potential between any two points in an electrostatic field is the integral of the electric force along any path joining the two points; taking any two points on the conductors, and taking a path joining these two points lying entirely in the conductors, the integral along this path of the electric force produced by the charges is very nearly equal and opposite in sign to the integral along this path of the electric force produced by the alternating flux. But going back to the picture of this last electric field (Fig. 13), we see that this integral is proportional to the number of turns which the path makes about the core. Thus the potential due to the charges changes uniformly along the conductors of the solenoid.

In the conductors of the solenoid, then, the field due to the charges is very nearly opposite to that due to the alternating flux. Hence the field of the charges produces a power flow into the conductors very nearly equal to the power flow out produced by the field due to the alternating flux. Now let us trace the power flow from the leads to the various turns of the solenoid. Suppose we have a one layer winding and that the leads are brought out as in Fig. 15. The nature of the power flow from *AB* to *CE* has already been discussed under the transmission line first treated. Now consider the flow between *CD* and the solenoid *ED*. The magnetic field is practically that of the lead *CD* alone. The difference in potential between the lead and the solenoid decreases progressively from *EC* to *D*. Thus the hori-

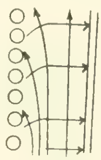


FIG. 16

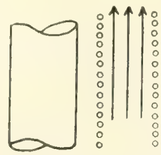


FIG. 17

zontal component of the electric field decreases from *EC* to *D*, and hence the power flow which enters at *CE* proceeds upwards along *CD* but diminishing in intensity towards *D*. Next to the solenoid there is a potential drop from turn to turn, and hence the elecric force has a vertical component there. Thus the lines of electric force from solenoid to lead *CD* are bent curves as shown in Fig. 16. Thus from *EC* to *D*, power is diverted progressively into the solenoid as in Fig. 16. Without great difficulty the way this power spreads out around the turns could be traced out.

Now suppose that the core is not non-conducting, but that it is laminated. Then charges form on the surfaces of the laminations which reduce the field within the iron to nearly zero. This has the effect of taking the electric field shown in Fig. 13 and confining it to the insulating spaces between the laminations. Thus at the same time the power flow is also confined to these insulating spaces. From the point of view developed here, the purpose of laminating a core is to furnish insulating paths whereby the magnetic energy may flow into its interior.

TRANSFORMER

Suppose a second similar solenoid (Fig. 17) wound

round the core which we have been studying. When the transformer is operating, the current in the inner primary coil is opposite in magnetic sense and nearly equal to the current in the outer or secondary coil. Hence the magnetic field obtained now will differ from that considered in the reactance just considered, only in the large magnetic field between the two coils. Taking this magnetic field together with the electric field due to the alternating flux (Fig. 13), we get a flow of power across the intervening space from the primary to the secondary. There is still to be considered the fields produced by the charges on the coils. Consider the electric field as the sum of two component fields, E_1, the field produced by the charges on the primary, and E_2, the field produced by the charges on the secondary. Also consider the magnetic field as the sum of two component fields H_1, that produced by the primary current alone and H_2, that produced by the secondary current alone. Then to get the whole Poynting vector, consider the Poynting vectors of the combinations E_1, H_1, E_2 H_2, E_1 H_2, E_2 H_1. The first, the power flow given by the electric field due to charges on the primary and the magnetic field of the primary current has already been given for the reactance coil. (Figs. 15 and 16). It gives the flow of power from the primary leads to the primary winding. The second combination— E_2 H_2 — is entirely similar. It gives the flow of power from the secondard winding out to the secondary leads. The combinations E_1 H_2 and E_2 H_1 by Appendix II, give Poynting vectors which correspond only to local circulations of energy in the dielectric medium and hence need not be considered. Thus the electric field due to the alternating flux, together with the "leakage" magnetic field direct the power from the primary coil into the secondary.

THE DIRECT-CURRENT GENERATOR

Consider next the direct-current generator, first separately excited and under no load. This differs from the cases treated as the effect of motion on the electromagnetic conditions in a body must be taken into account. An electric charge moving in a magnetic field experiences a side thrust which is perpendicular to the direction of motion of the charge and perpendicular to the magnetic force. The magnitude of this thrust is proportional to the product of charge, velocity, magnetic force, and the sine of the angle between the velocity and magnetic force. The conductors on the armature have in them charges (electrons) which are free to move. The rotation of the armature carries these electrons around through the magnetic field. Due to this rotation, the electrons are acted upon by forces parallel to the axis of rotation, the reactions of the magnetic field upon their motion. These forces, however, can only produce a small displacement of the electrons because they carry electrons to the surfaces of the conductors at the end connections and commutator bars forming free charges, and these free charges set up an electrostatic field which acts on the electrons in the conductors in the opposite direction to the magnetic reactions on the electrons. Thus in the direct-current machine there is set up an electrostatic field. This field has a considerable value inside the conductors as well as in the insulating spaces, but no current is produced because this electric field is just balanced in its action on the electrons by the magnetic field reacting on the moving electrons. The electric force in the conductors being thus equal to the magnetic reaction upon the moving electrons, the integral of the electric force along a conductor, that is the change of electric potential along the conductor, can be calculated entirely from the magnetic reactions, which gives the usual cutting lines of force rule.

The electric field then within the conductors consists of lines of force parallel to the axis of the armature. This electric force is a maximum where the magnetic reaction is a maximum, that is, under the poles, and this force is zero in a conductor lying between the poles. The force changes sign as the conductor passes from under one pole to the next pole. Just outside of any conductor we have besides this parallel force, lines of force normal to the surface which originate surface charges there.

What is the Poynting vector distribution corresponding to this electric and magnetic field? Here portions of one set of conductors, the armature, are maintained at different potentials and an electric field produced. In an entirely different set of conductors, the field coils, electric currents flow and produce a magnetic field. The resulting Poynting vector (as is shown in Appendix II) corresponds to an energy flow which only circulates locally in the dielectric media. Hence we shall not consider this no load condition further.

Now suppose that the generator delivers load. Then the armature currents produce an additional magnetic field which must be considered. Inside the conductors the electric and magnetic fields are disposed as in Fig. 1. Here, however, the electric current is opposite in direction to the electric force, so that the magnetic field and, therefore, also the Poynting vector will be opposite to that found for Fig. 1. Thus electric power originates uniformly over the cross section of the conductors and travels radially outward to the surface. This power generation is appreciable, however, only where there is appreciable electric field in the conductors, that is, only under the poles. This power comes into the conductor, of course, by mechanical means, that is there is a mechanical force acting upon the moving conductor when electric power is being generated in it. After leaving the conductors, the power travels out toward the brushes and along outside the power line in a way that has already been elucidated for the transmission line and transformer. If we include in the external load the field windings, we arrive at the shunt and series excited generators. In the direct-current motor all conditions are the same except that the armature current flows in the direction of the

electric force. This reverses the Poynting vector so that power flows into the armature conductors where it changes to mechanical power.

THE ALTERNATING CURRENT GENERATOR

In an alternating-current generator with a rotating field, we have first to consider the electric field which the rotating flux by itself would set up. As before, we go back to the fundamental law of induction which we have stated above: if at any point the magnetic flux is increasing in a given direction, that increasing flux sets up an electric field in exactly the same manner as a magnetic field would be set up by a current at that point and in that direction. Hence, to get a picture of the electric field, at any instant, we should imagine placed at each point of the space occupied by the generator, a vector or arrow whose direction gives the direction in which the magnetic flux is changing at that moment.

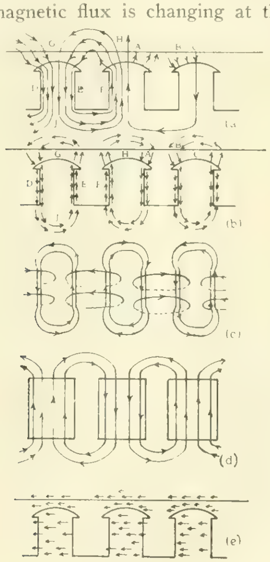


FIG. 18

Then we may space these arrows so that they are dense where the magnetic flux is changing rapidly and sparse where the flux is changing slowly. The ensemble then gives the curves of flux increase or as Heaviside calls them lines of flow of the "magnetic displacement current."

Fig. 18 (a) shows a section of a portion of rotor and stator of an alternator taken in a plane perpendicular to the axis of rotation. The arrowed curves are lines of flux and are omitted in places for clearness. The direction of motion of the rotor is from right to left. Now plot for various points the arrows showing the direction of change of magnetic flux. At the point A at the instant shown in Fig. 18 (a), the flux is directed upwards, but it is decreasing in density because of the rotor's motion. Hence at A the flux is increasing in a downward direction and in Fig. 18 (b) at A, we place arrows pointing downwards. At point B in Fig. 18 (a) the flux is directed downwards and is increasing in density. Hence there the flux is increasing downwards and in Fig. 18 (b) we place arrows at B pointing downwards. At C in Fig. 18 (a) the flux momentarily is not changing and hence at C in Fig. 18 (b) we place no arrows.

At the point G in Fig. 18 (a) the downward component of flux is diminishing, and the horizontal component is increasing. Hence at G in Fig. 18 (b) the arrow showing the direction of flux increase is directed upwards and to the left. At H in Fig. 18 (a) the vertical component of flux is not changing, but the horizontal component of flux just before the moment shown in the figure was pointing to the left and a moment later will be pointing to the right. Hence the arrow in Fig. 18 (b) at H is horizontal and points to the right.

The point D, which at the time shown lies in the forward face of a pole, a moment earlier was lying in the empty space ahead of the pole. A moment later it will be in the body of the pole. Thus the flux density at D changes very rapidly from the weak leakage flux ahead of the pole to the strong downward flux density in the pole itself. Hence at D in Fig. 18 (b) we draw arrows densely spaced and pointing downwards. Continuing in this way we may draw the flux change arrows at every point in space obtaining a distribution as shown in Fig. 18 (a).

Fig. 18 (c) shows the flux change lines or lines of magnetic displacement current, with the material structure of the alternator omitted for clearness. It is easy to see now how the field of electric force set up by these magnetic currents will look. Lines of electric force are shown in Fig 18 (c). They are the half dotted curves linking the magnetic displacement currents. Fig. 18 (d) shows a view looking down on the tops of the poles. The closed curves are lines of electric force.

In addition to this electric field, we have the field produced by the charges which collect on the surface of the stator conductors. These charges appear in such a way as to reduce the electric force within the conductors very nearly to zero. That is, within the conductors the field produced by the charges is very nearly equal and opposite to that produced by the rotating field.

Let us first examine the power flow under no load conditions. We consider the magnetic field of the rotor in combination with each of the two electric fields just described. The combination with the latter electric field is of the class dealt with in Appendix II, namely an electric field produced by charges on one set of conductors whose parts are maintained at different potentials, the armature conductors, and a magnetic field produced by currents in another set of conductors, the field windings. This gives a power flow which merely circulates in closed loops in the dielectric medium and will not be considered further.

Take now the magnetic field together with the electric field which is produced by its rotation. From

Figs. 18 (a to d) we are able easily to combine them and find the distribution of the Poynting vector. Fig. 18 (e) shows the Poynting vector at various points. We see that the general direction of the vector is the direction of motion of the rotor. The vector depicts, in fact, the motion of the magnetic energy in space.

Passing now to load conditions, let us first consider a 100 percent power-factor load. The armature currents have their maximum value opposite the pole faces. The current distribution is shown in Fig. 19. We now have to consider the additional field produced by the armature currents alone. This is shown in Fig. 19. The change in the flux produced by the armature currents induce an electric field. However, although the armature m.m.f. may be large, in the 100 percent power-factor position the reluctance of the magnetic path offered is very high, so that the flux produced by the armature currents is very small. Hence the electric field produced by the change of the flux which is due to the armature currents alone, is very small and will be neglected here.

There are then two magnetic fields, the one produced by the field currents and the one produced by the armature currents, and the two electric fields, the one produced by the charges on the armature conductors and the other produced by the changing position of the first magnetic field. The combination of the first magnetic field with the first electric field is a case which comes under Appendix II and, therefore, its Poynting vector will not be considered further. The combination of the first magnetic field and the second electric field has already been considered. Its Poynting vector gave the flow of the magnetic energy accompanying the rotor. The combination of the second magnetic field and the first electric field has already been considered in detail in the apparatus previously treated. Its Poynting vector shows power originating with uniform density over the cross section of the armature conductors, flowing straight out to the surface of the conductors and thence out to the terminals of the machine through the dielectric spaces.

The only new feature here is the combination of the second magnetic field with the second electric field, which, of course, must show how the power which the preceding field pair removes from the conductor gets into the conductors.

Comparing [illegible] and 19, we readily get for the Poynting vector Fig. 20. In obtaining this result it should be remembered that the magnetic force at any point is equal to the flux density at the point divided by the permeability of the medium, so that in Fig. 19 while the magnetic field in the air-gap is very large, in the iron portions of the magnetic circuit it is very small. Hence the Poynting vector in Fig. 20 is principally confined to the air-gap. The lines of power flow originate at the tips of the pole pieces where mechanical energy is being supplied, and flow inward through the air gap into the armature conductors.

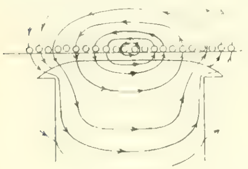


Fig. 19

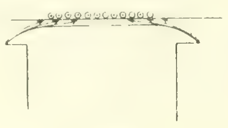


Fig. 20

THE SYNCHRONOUS MOTOR AND CONDENSER

In a synchronous motor, all conditions will be the same as described for the generator except that the armature currents will be reversed. This has the effect of reversing only those Poynting vectors which are due to the magnetic field produced by the armature currents and which are shown in Fig. 20. Thus electrical power is carried up to the armature conductors through the dielectric space and thence crosses the air gap entering the pole pieces where it is transformed into mechanical power.

Assume a synchronous motor running idle on the line and excited for 100 percent power-factor. Then conditions are just the same as described for the unloaded generator in Fig. 18. Now suppose we raise the excitation. Then we have a synchronous condenser drawing leading current from the line. To follow power flow here we may start from the 100 percent no load condition which we have already studied and consider the added effect of the increase in field current and the armature currents.

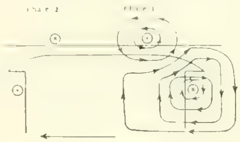


Fig. 21

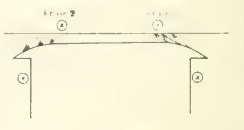


Fig. 22

The increase in the field current and the armature currents produce m.m.f.'s which are opposing as far as concerns the main magnetic circuit. They will produce, therefore, only a leakage flux which is shown in Fig. 21. For simplicity a two-phase concentrated winding is shown, and the time shown is when the generated voltage is 0.707 times its maximum value in either phase.

Of course, this leakage flux as it changes its space position will induce an electric field, but as has been explained before this electric field will be small compared to that induced by the changing space position of the main flux and will be neglected here. We have left then to consider the combination of this magnetic field with the electric field produced by the charges on the armature conductors, and the combination with the electric field induced by the main flux.

The first combination gives the flow of power from the machine terminals to the machine windings and has been considered before. The second combination, as

will be seen by comparing Figs. 18 and 21, leads to the power flow shown in Fig. 22. Power leaves phase *2* and crosses the air-gap and enters the advance pole tip, where it changes to mechanical power in the form of a force tending to accelerate the rotor. This mechanical power is transmitted by the internal mechanical stresses of the rotor to the other pole tip, where it is reconverted into electrical power, a force appearing at this rear pole tip tending to retard the rotor. Thus the resulting mechanical torque on the rotor is zero. The power which leaves the rear pole tip crosses the air gap and enters phase *1*. Thus in the synchronous condenser there is an exchange of power between the phases, but it is not a direct electrical exchange, but a change into mechanical power and then back into electrical.

THE INDUCTION MOTOR

The power flow in an induction motor is now easy to follow. The rotating magnetic flux produces an

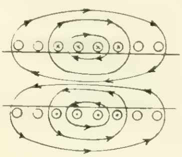


FIG. 23

electric field similar to that of Fig. 18 (c). This combined with the leakage magnetic field between primary and secondary currents, Fig. 23, produces the flow of power from the primary conductors across the air gap into the secondary conductors, where it is changed partly into Joulian heat and partly into mechanical work.

The object of this paper is to give a picture of the way the media which support the electromagnetic fields, namely the insulating materials and aether, although not considered at all by the designers of electrical machines, play a vital role of leading the electrical power to where it is consumed. It is intended to give merely an entertaining picture of the facts of power flow in the light of the Maxwell theory. It is not a thesis for advocating the use of more aether and less material in electrical machines.

APPENDIX I

Where the electric and magnetic fields are respectively given as the sum of several electric or magnetic fields, the Poynting vector may be obtained by adding together the Poynting vectors corresponding to the combination of each component electric field with each component magnetic field. This follows from the distributive law of multiplication for vector products. For from the definition, the Poynting vector S is given by:

$$\mathbf{S} = \frac{c}{4\pi}\,[\mathbf{E} \times \mathbf{H}]$$

Here the bold face type denotes vectors, and the cross, vector multiplication. If, now;—

$$\mathbf{E} = \mathbf{E}_1 + \mathbf{E}_2 \text{ and } H = \mathbf{H}_1 + \mathbf{H}_2 \text{ we have:}$$

$$S = \frac{c}{4\pi}\,[(\mathbf{E}_1 + \mathbf{E}_2) \times (\mathbf{H}_1 + \mathbf{H}_2)] = \frac{c}{4\pi}\,[\mathbf{E}_1 \times \mathbf{H}_1] + \frac{c}{4\pi}\,[E_2 \times H_2] + \frac{c}{4\pi}\,[\mathbf{E}_2 \times \mathbf{H}_1] + \frac{c}{4\pi}\,[\mathbf{E}_1 \times \mathbf{H}_2]$$

APPENDIX II

If different parts of one set of conductors are maintained at different potentials thus producing an electrostatic field, and if currents flow in certain other conductors producing a magnetic field, the Poynting vector corresponding to the combination of this electric and this magnetic field gives a power flow which merely circulates locally in the dielectric medium.

We have, if E and H are respectively the electric force and magnetic force in the fields described above and S is the Poynting vector;—

$$\mathbf{S} = \frac{c}{4\pi}\,[\mathbf{E} \times \mathbf{H}]$$

Hence;—

$$div\,\mathbf{S} = \frac{c}{4\pi}\,div\,[\mathbf{E} \times \mathbf{H}] = \frac{c}{4\pi}\,(\mathbf{E} \cdot curl\,\mathbf{H} - \mathbf{H} \cdot curl\,\mathbf{E})$$

where the dot denotes scalar multiplication. Now since the only electric field is an electrostatic one, curl E is identically zero. Hence;—

$$div\,\mathbf{S} = \frac{c}{4\pi}\,(\mathbf{E} \cdot curl\,\mathbf{H})$$

Outside the conductors which are carrying current curl $H=0$. Hence outside these conductors div $S=0$. Inside these conductors $E=0$. Hence here also div $S=0$. Thus div $S=0$ everywhere. Hence the lines of S can have no beginning or end but must form closed loops.

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country. The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

JULY 1919

Removing and Replacing Railway Motor Armature Shafts

There are four general methods of mounting the commutator and core on a railway motor armature shaft. On the more modern motors, especially of the smaller sizes for low floor cars, the iron is built directly on the shaft and held in place by a nut at the commutator end; this type is used mostly on the ventilated type motors having longitudinal ventilating ducts through the core and a fan at the rear end. Where space is available the spider type of construction is also used The other two types mentioned below have been superseded, as it is necessary to disconnect the armature leads from the commutator when a shaft is to be replaced. Some of these older type shafts have wiper rings screwed on the shaft, but this practice has been changed to a shrunk-on type of wiper on the more modern motors.

IRON BUILT ON SHAFT—NUT AT COMMUTATOR END

In Fig. 1 is shown the construction in which the armature iron and commutator bushing are mounted directly on the shaft and depend upon the press fit, the key, and the lock nut at the commutator end to keep them in place. The fan and commutator end wiper ring which have been shrunk on, are removed by heating them with one or more blow torches

(keeping the shaft cool by wrapping it with wet asbestos) and driving them off with a hammer and chisel. After the fan and wiper are removed, clamp the core and commutator together by placing over the shaft two pieces of iron pipe, one on each end, large enough to clear the armature nut and long enough so that the plates placed over the shaft and against the pipes will clear the end of the commutator and the end

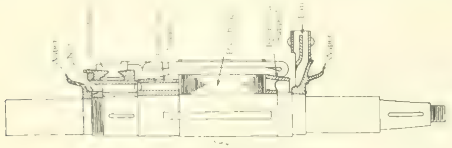


FIG. 1—IRON BUILT ON SHAFT
Nut at Commutator End.

of the coils at the pinion end, as shown in Fig. 5. Bolt the plates together, using four or more bolts just clearing the outside of the armature. Take special care to cut the pipes off square and to pull the bolts up evenly to prevent warping the core when the shaft is removed. Allow clearance enough at the pinion end between the plate and the shaft so that the key will clear. Another form of clamp has rings machined to fit the commutator and rear coil support, with bolts through the longitudinal vent ducts. When the clamp is in place, back off the lock nut at the commutator end, press out the shaft by applying pressure at its commutator end, and replace with a new one. With the new shaft in the core, apply and tighten the armature nut, remove the clamp and shrink on the fan and wiper ring.

SPIDER CONSTRUCTION

In Fig. 2 is shown the construction where the armature iron and commutator bushing are mounted on a spider, which

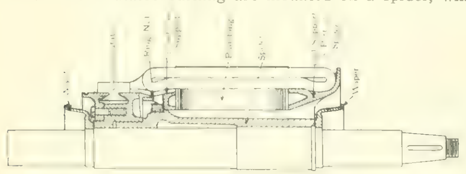


FIG. 2—IRON BUILT ON A SPIDER

is, in turn, mounted on the shaft. The commutator end wiper and the fan are shrunk on. To remove the shaft, take off the pinion end wiper ring (or fan, if a fan is used) by heating as described above. With this type it is not necessary to remove the commutator end wiper, as it comes off with the core. Pressure is applied at the commutator end of the shaft in removing. The new shaft is pressed in and after it is in place, the commutator end and pinion end wiper or fan are

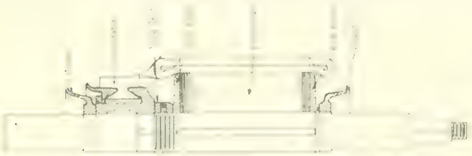


FIG. 3—IRON BUILT ON SHAFT
Nut between Commutator and Core.

shrunk on. This method applies both to spiders with separate rear end bells and to spiders with rear end bells cast integral.

IRON BUILT ON SHAFT—NUT BETWEEN COMMUTATOR AND CORE

In Fig. 3 the commutator spider and core are shown mounted directly on the shaft with a ring nut between the commutator and the core. With this type of construction, it is necessary to lift the armature leads out of the commutator neck, remove the wiper rings and pull the commutator first. The commutator is provided with tapped holes for bolts to aid in this operation. After the commutator is removed, clamp the core together, using a modification of the clamping device shown in Fig. 5, back off the ring nut, and press out the shaft, applying pressure at the commutator end. After the new shaft is in place, apply the ring nut to secure the core, press on the commutator, shrink on the wiper rings and reconnect the windings.

IRON BUILT ON SHAFT—NUT AT PINION END

In Fig. 4 is shown a type in which there is a shoulder on the shaft between the commutator and core. In this case it is necessary to disconnect the windings the same as for Fig. 3. Remove the wiper rings and pull the commutator as described above. Clamp the core together, back off the ring

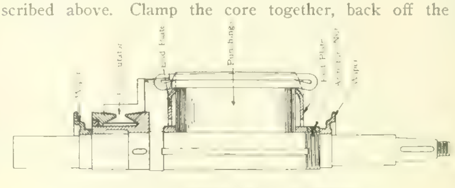


FIG. 4—IRON BUILT ON SHAFT
Shoulder between Commutator and Core.

nut at the pinion end and press out the shaft, applying pressure at its pinion end. Press in the new shaft and apply the ring nut, which should be drawn up tight before the clamp is removed. Replace the commutator and reconnect, then shrink on the wiper rings.

PRECAUTIONS

In connection with the replacing of shafts of railway motor armatures, the following points should be kept in mind.

1—A little white lead on the shaft at the fit before pressing on acts as a lubricant and prevents rust.

2—New shafts should have fillets at all changes in diameter, as this tends to prevent breaking of shaft.

3—New shafts should be made about 0.004 in. larger than the original shaft at the press fit, to insure the proper tonnage in pressing them in.

4—Check the clearances between the top of the key and the key seat in the core to prevent binding at this point.

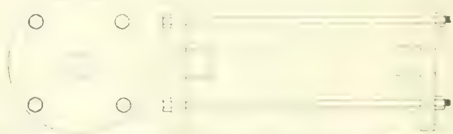


FIG. 5—CLAMP FOR HOLDING ARMATURE WHILE SHAFT IS REMOVED

5—Chamfer the start of the commutator bore to allow the shaft to enter straight and get an even start.

6—Shafts should be pressed in at approximately 20 to 25 tons on motors from 25 to 50 hp and about 40 to 50 tons for sizes above 50 hp.

7—Wherever possible, the armature nut should be removed and replaced while the clamps are in place.

8—Shafts will press at approximately 1.5 to 2 times the tonnage used when they are pressed in, because of slight rusting and flowing of metal.

9—The press fit will vary, depending upon the material of the core. Steel or malleable iron can safely stand a higher tonnage than cast iron.

F. A. ASHWORTH

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Short-Circuit Calculations

As transmission and distribution systems grow, interconnections between systems or the parts of a single system are made, and the result is a network of circuits of more or less complicated form. The saving in transmission losses due to this paralleling of the circuits supplying power to any given part of the system becomes large, and this saving, together with the increased continuity of service secured, makes such interconnections most desirable. In order, however, to realize the full advantages thus obtainable, the problems of protecting one part of the network against short-circuit conditions appearing in other sections must be intelligently dealt with by proper relay and circuit breaker applications. This necessitates the solution of the network to determine the probable current during short-circuit conditions and, while it is possible to obtain a solution mathematically by the application of Kirchoff's laws, the process is often so laborious that guesswork is resorted to. Three articles in this issue of the Journal are of particular interest and value in that they describe means of lessening the labor involved in the usual methods of calculating networks.

The article by Mr. Woodward describes a testing board with which the problems are solved by using a miniature network with resistances proportioned to the reactance of the actual network. It allows for the paralleling of the sources of energy, and of the circuits corresponding to the power system, and provides for the placing of a short-circuit at any point and measuring the short-circuit current. The only mathematical work involved is the multiplication of the current reading in the network by a constant. This testing board is the logical development of the method of building up a miniature network of uniform resistance wire, whose length is proportional to the reactances of the circuits, which has been commonly done for several years. The function of the testing board is to simplify greatly the setting up of the miniature network.

The other articles deal with methods for simplifying the mathematical work and so provide a means which can be utilized by engineers to whom a testing board may not be available. Mr. Evans describes the practical use of the various methods while Mr. Fortescue gives their development. These methods also make it possible to obtain high accuracy by the use of complex quantities in the calculation both of short-circuit currents and of regulation for any assumed load condition. An interesting and valuable feature is the automatic check obtained on the values of mutual impedance.

While it is believed that several of the methods of simplified calculation are here published for the first time, they have been in constant use by the authors and their associates for several years and have proven their value repeatedly in the saving of time and labor, and in the securing of accurate values, where the extensive calculations required without these short-cut methods would hardly be warranted. Engineers of other organizations cooperating with these engineers, have used the methods here outlined and have appreciated the simplification introduced by them in the solutions of networks. These principles are not limited to a particular form of net work but are of general applicability. As they have proven their value in the study of individual networks, so they will be of still greater value in the study of interconnected systems. Power is already being fed into several large networks by power stations separated by many miles. California has interconnected high-tension transmission lines hundreds of miles in length; and the interconnection of all the generating stations along the Atlantic seaboard into one huge system is no longer a dream, but a subject for serious consideration. As such systems become larger the calculation of short-circuit currents, regulation, size and type of reactance coils, circuit breakers and relays, which are essential to the successful operation of such networks, become of increasing complexity.

To classify all possible variations of networks and to give formulas for their solution in detail would be a superhuman task. On the other hand, a strictly general solution, while satisfactory from a mathematical point of view, is not of much practical value; it is altogether too general.

Facility in solving networks comes with practice and this cannot be over emphasized. The simpler and fewer the principles used the better. Many networks which appear at first to be extremely complicated can, on analysis, be resolved into relatively simple elements.

Any means by which mathematical processes in the solution of vital problems may be shortened or simplified is welcomed by the engineer. These articles deserve careful study because of the growing importance of the knowledge of network characteristics to the system designer and operator. A. W. COPLEY

Electrical Characteristics of Transmission Circuits-II

Wm. Nesbit

REACTANCE

A CONDUCTOR carrying an electric current is surrounded by a magnetic flux, whose value is proportional to the current. If the current varies, this flux also changes, thereby inducing an electromotive force in a direction which opposes the change. This counter e.m.f. is proportional to the rate of change and hence in alternating current is proportional to the frequency. It can be expressed in ohms per mile of each conductor of a single-phase or of a symmetrical three-phase circuit as follows:—

Ohms Reactance $= 2 \pi f L$ (9)

When $f =$ Frequency in cycles per second

$L =$ Henries per mile of single conductor.

The value for $2 \pi f$ are as follows:—

Frequency	$2 \pi f$
1	6.28
15	94.25
25	157.1
40	251.3
60	377.0
133	835.7

Tables IV and V indicate the reactance in ohms per mile, of a single conductor at 25 and 60 cycles respectively for various spacings of conductors. The foot notes to these tables cover the pertinent points relating to them. The resistance per 1000 feet, and per mile of single conductor at 25 degrees C. (77 degrees F) is given in parallel columns as a convenience for comparison of the resistance and reactance values. The resistance corresponding to other temperatures when desired may be taken from Tables I and II.

Tables VI and VII indicate the relative importance of reactance and resistance. In some cases of short lines and large single conductors, the reactance and not the resistance may determine the size and number of cables necessary. In other words, it may be necessary to keep the resistance abnormally low so that the reactance will not be so high as to result in an abnormal voltage drop in the circuit. In such cases the values in Tables VI and VII may be used for determining the permissible resistance in order not to exceed the desired reactance.

Example. It is desired to use 1 000 000 circ. mil single conductor cables at 60 cycles, spaced two feet apart; from Table VII it is seen that the reactance drop under these conditions is 8.52 times the ohmic drop at 25 degrees C. If an ohmic drop of five percent at 25 degrees C is suggested the corresponding reactive drop would be 5×8.52 or 42.6 percent which would be excessive. If it is desired to limit the reactive drop to 10 percent in this case, the ohmic drop at 25 degrees C must be $10 \div 8.52$ or 1.18 percent.

Probably a more important use for Tables VI and VII is for determining the reactance of a conductor directly from its resistance. To do this it is only necessary to multiply its resistance (at 25 degrees C) by the ratio value in table VI or VII corresponding to the conductor and spacing desired.

UNSYMMETRICAL SPACING

The inductance and capacitance per conductor of a three-phase circuit for symmetrical spacing of conductors is the same as the inductance and capacitance per conductor of a single-phase circuit for the same size conductor and the same spacing. For irregular spacing of conductors, the inductance and capacitance will be different. When the three conductors are placed in the same plane (flat spacing), the inductance of each of the outside conductors is greater than that of the middle conductor. By properly transposing the conductors, the inductance and capacitance may be equalized in all three conductors. However, the effect of flat spacing is equivalent to that of a symmetrical arrangement of greater spacing.

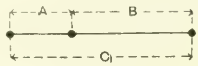


FIG. 7

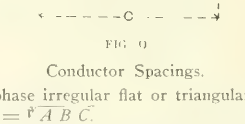


FIG. 8

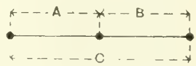


FIG. 9

Conductor Spacings.

For three-phase irregular flat or triangular spacing (Figs. 7 and 8) use $D = \sqrt[3]{A B C}$.

For three-phase regular flat spacing Fig. 9 use $D = 1.26 A$.

For two-phase line the spacing is the average distance between centers of conductors of the same phase. It makes no difference whether the plane of the conductors with flat spacing is horizontal, vertical or inclined.

Various arrangements of conductors are indicated in Figs. 7, 8 and 9. Many three-phase high tension circuits have the three conductors regularly spaced in a common plane (regular flat spacing) Fig. 9. Beneath these figures are placed statements indicating the determination of "effective spacings" for any arrangement of conductors.

Since the so called "effective spacing" corresponding to unsymmetrical arrangements of conductors is usually a fractional number, the line constants for such effective spacing can usually not be taken directly from

the tables but may be obtained by the use of the values in columns A and B at the foot of these tables.

Example:—It is desired to determine the 60 cycle reactance per mile of a single conductor for flat spacing of 11 ft. between adjacent 0000 solid copper conductors. The effective spacing is 1.26 × 11 or 13.8 feet. The reactance (Table V) for this conductor at 13 feet symmetrical spacing is 0.820 ohm. The value for A, (bottom of Table V) = 13.8 ÷ 13 = 1.06. The value of B corresponding to the value for A of 1.06 is approximately 0.006 which, added to 0.820 gives a reactance of 0.826 ohm for the effective spacing of 13.8 feet. The values of reactance for all effective spacings not included in the Table may be determined in a similar manner.

With an unsymmetrical arrangement of conductors there must be a sufficient number of transpositions of conductors to obtain balanced electrical conditions along the circuit.

CAPACITANCE

When mechanical force is exerted against a liquid or a solid mass, a displacement takes place proportional to the force exerted and inversely proportional to the resistance offered by the liquid or solid mass subjected to the force. If the mass consists of some elastic material, such as rubber, the displacement will be greater than if it consists of a more solid material, such as metal.

In a similar manner when an e.m.f. is applied to a condenser, a certain quantity of electricity will flow into it until it is charged to the same pressure as that of the applied circuit. A condenser consists of plates of conducting material separated by insulating material known as the dielectric. All electric circuits consist of conductors separated by a dielectric (usually air) and therefore act to a greater or less extent as condensers. The ability of a condenser or any electric circuit to receive the charge is a measure of its "capacity" more properly known as its "capacitance". Just as the rubber mass referred to above will, for a given force, permit of greater displacement so will circuits of greater capacitance permit more current to flow into them for a given e.m.f. impressed.

The process of charging a dielectric consists of setting up an electric strain in it similar to the mechanical strain in a liquid or mass referred to above. If an alternating voltage is impressed upon the terminals of a circuit containing capacitance, the charging current will vary directly with the impressed e.m.f. There is current to the condenser during rising and from the condenser during decreasing e.m.f. Thus the condenser is charged and then discharged in the opposite direction during the next alternation, making two complete charges and discharges for each cycle of impressed e.m.f. (Fig. 10). As long as the e.m.f. at the terminals is changing, the condenser will continue to receive or give out current. The current flowing to and from the condenser, assuming negligible resistance, leads the impressed e.m.f. by 90 electrical degrees.

DEFINITION

The capacitance of a circuit or condenser is said to be one farad when a rate of change in pressure of one volt per second at the terminals produces a current of one ampere. Stated another way, its capacitance in farads is numerically equal to the quantity of electricity in coulombs which it will hold under a pressure of one volt. The farad being an inconveniently large unit, one millionth part of it, the microfarad, is the usual practical unit.

CAPACITANCE FORMULA

An exact formula for the capacitance between parallel conductors must take into account the nonuniformity of the distribution of charge around the conductors. Such a formula* is formed by considering the charges as concentrated at the inverse points of the conductors; thus,—

$$C = \frac{0.008467}{\cosh^{-1}\frac{D}{d}} \qquad (10)$$

Where C equals the microfarads per 1000 feet of conductor between two parallel bare conductors in air, D, the distance between centers of the conductors and d, the diameter and R the radius of the conductors measured in the same units as D.

$$\text{Since } \cosh^{-1} X = \log_\epsilon \left(X + \sqrt{X^2 - 1}\right) \qquad (11)$$

$$C = \frac{0.008467}{\log_\epsilon \left(\frac{D}{d} + \sqrt{\left(\frac{D}{d}\right)^2 - 1}\right)} \qquad (12)$$

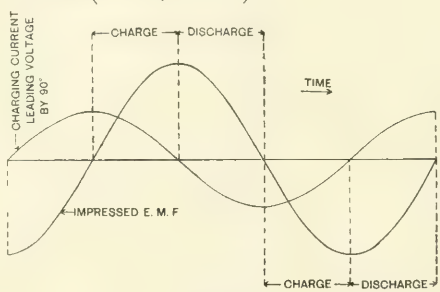


FIG. 10—CHARGING CURRENT

Reducing to common logarithms and capitance to neutral,—

$$C = \frac{0.007354}{\log_{10} \left(\frac{D}{d} + \sqrt{\left(\frac{D}{d}\right)^2 - 1}\right)} \qquad (13)$$

Microfarads per 1000 feet of single conductor to neutral.

or

$$C = \frac{0.038829}{\log_{10} \left(\frac{D}{d} + \sqrt{\left(\frac{D}{d}\right)^2 - 1}\right)} \qquad (14)$$

Microfarads per mile of single conductor to neutral.

When D is greater than 10 d, which is always the case in high-tension transmission lines employing bare conductors, the following simplified formulas may be used with negligible error.—

$$C = \frac{0.007354}{\log_{10}\frac{D}{R}} \qquad (15)$$

*See article by Pender & Osborne in *Electrical World* of Sept. 22, 1910, Vol. 56.

TABLE IV—RESISTANCE AND 25 CYCLE REACTANCE

OHMS PER MILE OF SINGLE CONDUCTOR

CONDUCTORS: MATERIAL, TYPE, DIAMETER IN INCHES, B & S NO., AREA IN CIRCULAR MILS.

RESISTANCE OF A SINGLE CONDUCTOR IN OHMS AT 25° C (77° F) xx, PER 1000 FEET and PER MILE.

REACTANCE IN OHMS PER MILE OF EACH CONDUCTOR OF A SINGLE PHASE, OR OF A SYMMETRICAL 3 PHASE CIRCUIT. FOR OTHER ARRANGEMENTS OF CONDUCTORS SEE FOOT NOTES. x THE TABLE VALUES WERE DERIVED FROM THE EQUATION—OHMS REACTANCE $= 2\pi FL$ (L BEING EXPRESSED IN HENRIES PER MILE OF SINGLE CONDUCTOR.) THE REACTANCE FOR OTHER FREQUENCIES IS $\frac{F}{25}$ THE TABLE VALUES.

DISTANCE (D) BETWEEN CENTERS OF CONDUCTORS x

Material	Type	Diameter in Inches	B & S No.	Area in Circular Mils	Resistance per 1000 Feet	Resistance per Mile	1/2"	1"	2"	3"	4"	5"	6"	8"	12"	18"	2 Feet	3 Feet	4 Feet	5 Feet	6 Feet	7 Feet	8 Feet	9 Feet	11 Feet	13 Feet	15 Feet	17 Feet	19 Feet	21 Feet	23 Feet	25 Feet
COPPER	STRANDED	1.631		2 000 000	00554	0293			065	086	100	112	121	135	156	175	191	211	225	234	245	254	261	266	277	285	292	299	304	309	314	317
		1.548		1 800 000	00615	0325			068	089	103	114	123	138	158	178	193	214	228	240	248	256	262	269	279	287	294	301	306	312	316	320
		1.504		1 700 000	00652	0344			070	090	104	115	25	139	160	180	195	215	230	241	250	258	265	270	281	289	296	302	308	314	317	321
		1.459		1 600 000	00693	0367			071	091	106	117	127	141	161	181	196	216	231	244	251	260	266	272	282	290	297	304	309	315	319	324
		1.412		1 500 000	00739	0391			073	093	108	119	128	142	162	183	197	219	233	244	253	261	267	274	284	292	299	306	311	316	322	325
		1.364		1 400 000	00792	04 8			074	095	109	120	129	144	164	185	200	220	234	246	255	263	269	276	285	294	301	307	313	318	323	327
		1.263		1 200 000	00924	0489			078	099	113	124	133	148	168	188	204	224	238	250	260	266	274	280	290	297	305	312	318	322	327	330
		1.209		1 100 000	0101	0533			080	100	115	127	136	150	171	190	205	226	240	253	261	268	276	282	291	300	307	314	319	325	328	334
		1.152		1 000 000	0111	0588			083	104	117	129	138	152	173	194	208	229	244	255	263	271	279	285	294	302	311	315	322	326	330	336
		1.123		950 000	0117	.06 8			084	105	118	130	139	154	175	195	209	229	245	256	264	272	280	286	295	303	312	318	323	328	332	337
		1.093		900 000	0123	0650			086	106	120	132	141	155	176	196	211	230	246	258	265	273	281	286	296	305	312	319	323	330	334	338
		1.062		850 000	0130	0688			087	108	122	134	143	157	177	197	212	233	247	258	267	276	282	288	298	306	314	320	325	330	335	340
		1.031		800 000	0139	0735			089	109	124	135	144	158	178	200	214	233	248	260	268	277	284	290	300	308	315	322	327	332	337	341
		998		750 000	.0148	0782		055	090	110	125	136	146	160	181	201	216	236	251	262	271	279	286	291	301	310	318	323	328	334	339	344
		964		700 000	0158	0835		057	092	112	127	138	148	161	182	202	217	238	252	264	273	281	287	292	303	311	319	325	330	335	340	345
		929		650 000	0170	0900		059	094	114	129	140	149	163	183	205	218	239	254	266	274	282	289	294	304	313	320	327	333	337	342	346
		893		600 000	0185	0978		061	096	116	131	141	151	166	186	206	220	241	256	266	276	284	291	296	306	315	323	329	334	340	344	348
		855		550 000	0202	107		063	098	118	133	143	153	167	188	208	223	243	258	269	280	286	293	299	309	317	325	331	337	342	346	351
		815		500 000	0222	117		065	100	121	135	146	156	171	191	212	226	247	261	272	282	288	296	302	312	319	328	333	339	344	349	354
		772		450 000	0247	.131		068	103	124	137	149	158	173	193	213	228	248	263	274	283	291	298	304	315	322	329	336	342	347	352	356
		728		400 000	.0277	147		071	106	127	141	152	162	176	196	216	231	252	266	278	286	295	301	307	317	325	332	339	345	349	354	359
		681		350 000	0316	167		074	110	130	144	155	165	179	200	220	235	255	270	281	291	299	305	311	321	330	337	342	348	354	358	363
		630		300 000	.0370	196		078	113	133	148	159	168	182	203	224	238	258	274	284	294	302	308	315	324	333	339	346	352	358	362	366
		575		250 000	0444	235		083	118	138	153	163	173	187	209	229	244	264	279	290	299	306	314	319	329	338	345	352	358	360	365	371
		528	0000	211 600	0525	.277		087	122	143	157	168	177	192	213	233	248	268	283	294	303	310	318	322	332	341	350	355	360	365	371	376
		470	000	167 772	0662	350	.058	093	128	148	163	174	183	197	219	239	254	274	289	300	309	316	324	328	339	347	356	361	366	372	376	382
		418	00	133 079	0834	.442	.064	099	133	154	168	180	190	203	224	245	259	280	294	306	315	321	330	334	344	352	362	367	372	378	382	387
		373	0	105 560	105	555	.069	104	139	160	174	185	195	209	230	251	265	286	300	312	321	327	336	340	350	359	367	373	378	384	388	393
		332	1	83 694	132	.697	.075	110	145	166	180	192	200	214	236	257	271	292	306	318	327	333	341	346	356	364	373	380	385	390	395	399
		292	2	66 358	167	.883	081	116	151	172	186	197	216	220	242	263	277	298	312	323	333	339	347	352	362	370	379	384	390	394	399	405
		260	3	52 624	211	112	087	122	157	177	191	203	212	226	247	268	282	302	316	328	337	344	352	358	368	376	384	391	396	402	408	410
		232	4	41 738	266	141	.093	127	163	183	198	208	218	232	254	274	289	309	324	335	344	351	359	364	374	382	391	396	402	407	412	417
		206	5	33 088	336	178	099	133	168	189	203	214	224	238	259	279	294	314	328	339	349	356	364	370	380	388	395	402	407	413	418	422
	SOLID	.460	0000	211 600	0514	.272	.052	087	122	143	157	168	177	192	213	233	248	268	283	294	303	310	318	322	332	341	350	355	360	365	371	376
		.410	000	167 772	.0647	.342	.058	093	128	148	163	174	183	197	219	239	254	274	289	300	309	316	324	328	339	347	356	361	366	372	376	382
		.365	00	133 079	.0817	.432	064	099	133	154	168	180	190	203	224	245	259	280	294	306	315	321	330	334	344	352	362	367	372	378	382	387
		325	0	105 560	.103	.545	070	104	139	160	174	185	195	209	230	251	265	286	300	312	321	327	336	340	350	359	367	373	378	384	388	393
		289	1	83 694	.129	680	075	110	145	166	180	192	200	214	236	257	271	292	306	318	327	333	341	346	356	364	373	380	385	390	395	399
		.258	2	66 358	.163	862	081	116	151	172	186	197	206	220	242	263	277	298	312	323	333	339	347	352	362	370	379	384	390	394	399	405
		229	3	52 624	207	110	087	122	157	177	191	203	212	226	247	268	282	302	316	328	337	344	352	358	368	376	384	391	396	402	408	410
		204	4	41 738	260	138	093	127	163	183	198	208	218	232	254	274	289	309	324	335	344	351	359	364	374	382	391	396	402	407	412	417
		182	5	33 088	.328	173	099	133	168	189	203	214	224	238	259	279	294	314	328	339	349	356	364	370	380	388	395	402	407	413	418	422
ALUMINUM	STEEL REINFORCED	953		605 000	.0291	.154		060	095	116	130	142	151	166	186	206	220	241	256	267	276	284	291	296	308	315	322	328	335	340	344	348
		904		500 000	0352	.186		065	100	120	135	147	156	171	190	211	226	246	261	272	282	288	296	302	310	319	327	334	340	344	.350	355
		741		336 420	0525	.277		075	110	131	145	156	166	181	200	221	236	256	271	282	291	299	305	311	321	330	337	344	349	354	358	364
		635		266 800	0662	350		081	117	137	151	162	172	186	206	227	242	262	278	288	298	304	311	318	327	335	344	350	355	360	364	370
		564		211 950	.0834	.442		087	122	142	157	167	177	191	212	233	247	268	282	294	302	311	317	323	332	340	349	356	362	366	370	375
		501		167 800	105	.555		093	127	148	163	174	183	198	219	238	252	274	287	299	309	316	323	329	340	348	355	362	366	372	376	381
		447		133 200	132	697	064	098	134	154	169	179	189	204	224	244	259	279	294	305	314	322	329	335	345	353	360	368	373	378	.382	386
		398		105 530	.167	883	070	104	140	159	174	186	195	209	230	250	264	284	300	310	320	328	335	340	352	360	367	373	380	384	389	393
		355		83 640	211	1 12	075	110	145	166	180	192	200	216	236	256	271	291	304	316	326	334	340	348	356	365	373	379	385	390	393	397
		.316		66 370	.266	141	081	116	151	172	186	198	206	221	241	262	278	296	310	322	331	340	347	352	362	371	378	385	390	395	402	403
		281		52 630	336	178	087	122	157	176	191	203	212	227	248	268	282	303	317	329	337	346	352	358	368	377	385	390	395	.402	.405	410
		250		41 740	423	224	093	128	163	183	198	210	219	233	254	274	288	310	322	334	344	352	359	365	374	382	390	396	402	.407	.412	415

A	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175	180	185	190	195	200
B	002	005	.007	.009	011	013	015	.016	.019	020	022	024	025	027	028	030	.031	.032	034	035

x The reactance for any distance D not given in the table can be found as follows: Let E = the nearest smaller distance in the table. Divide D by E and taking a value of A nearest to the quotient find the corresponding value of B, which must be added to the reactance corresponding to the size of conductor and distance E.

For three-phase regular flat spacing use $D = 1.26\ A$. For three-phase irregular flat or triangular spacing use $D = \sqrt[3]{A\ B\ C}$. For a two-phase line the spacing is the average distance between centers of conductors of the same phase.

xx At a temperature of 65° C (149° F) these resistance values would be increased by 15 percent. They are based upon a conductivity for copper of 97.3—for aluminum of 61 percent. They do not take into account skin effect; this should be considered when the larger conductors are used, particularly at the higher frequencies. No allowance has been made for increased length due to sag when the conductors are two percent greater than for a solid rod of cross section equal to the total cross section of the wires of the cable.

For stranded conductors D was taken as the diameter of a solid rod of equivalent cross sectional area. Actually D for stranded conductors is slightly greater resulting in slightly less reactance than the table values. The table values are therefore conservative. In calculating the reactance values for the steel reinforced aluminum cable the presence of the steel strands was ignored.

TABLE V—RESISTANCE AND 60 CYCLE REACTANCE

OHMS PER MILE OF SINGLE CONDUCTOR

RESISTANCE OF A SINGLE CONDUCTOR IN OHMS AT 25° C (77° F) XX

REACTANCE IN OHMS PER MILE OF EACH CONDUCTOR OF A SINGLE PHASE, OR OF A SYMMETRICAL 3 PHASE CIRCUIT. FOR OTHER ARRANGEMENTS OF CONDUCTORS SEE FOOT NOTES. X THE TABLE VALUES WERE DERIVED FROM THE EQUATION—OHMS REACTANCE $= 2\pi FL$ (L BEING EXPRESSED IN HENRIES PER MILE OF SINGLE CONDUCTOR.) THE REACTANCE FOR OTHER FREQUENCIES IS $\frac{F}{60}$ THE TABLE VALUES.

DISTANCE (D) BETWEEN CENTERS OF CONDUCTORS X

MATERIAL	TYPE	DIAMETER IN INCHES	B & S NO.	AREA IN CIRCULAR MILS	PER 1000 FEET	PER MILE	½"	1"	2"	3"	4"	5"	6"	8"	12"	18"	2 FEET	3 FEET	4 FEET	5 FEET	6 FEET	7 FEET	8 FEET	9 FEET	11 FEET	13 FEET	16 FEET	17 FEET	19 FEET	21 FEET	23 FEET	25 FEET
COPPER	STRANDED	1631 1548 1504		2 000 000 1 800 000 1 700 000	.00554 .00615 .00652	.0293 .0325 .0344			157 163 166	207 212 216	241 246 251	268 275 277	290 297 300	324 330 334	374 380 384	422 428 432	458 463 468	507 514 515	540 550 552	563 575 580	589 597 599	610 615 620	627 630 637	640 647 648	665 673 675	684 690 695	700 707 710	720 724 725	730 736 740	742 750 752	755 760 763	761 770 773
COPPER	STRANDED	1459 1412 1364		1 600 000 1 500 000 1 400 000	.00693 .00739 .00792	.0367 .0391 .0418			170 174 177	219 223 226	255 259 262	281 284 288	304 309 310	338 342 346	388 390 394	435 442 444	472 474 480	520 525 527	555 560 563	585 588 591	603 609 613	625 627 633	640 642 648	655 659 663	678 683 687	698 702 707	715 718 723	732 735 738	742 749 752	758 760 765	765 770 775	778 780 786
COPPER	STRANDED	1263 1209 1152		1 200 000 1 100 000 1 000 000	.00924 .0101 .0111	.0489 .0533 .0587			187 192 199	237 241 248	270 277 282	299 304 310	320 326 332	356 360 366	404 410 416	451 458 465	490 494 500	537 543 550	574 577 585	598 607 612	625 627 634	642 645 650	657 663 669	672 676 685	696 700 707	715 720 725	732 739 745	750 755 758	765 767 773	773 780 783	785 787 793	794 803 807
COPPER	STRANDED	1129 1093 1062		950 000 900 000 850 000	.0117 .0123 .0130	.0618 .0650 .0688			201 205 209	251 255 259	284 288 292	312 317 320	335 338 342	370 372 376	420 422 426	467 470 474	502 508 510	552 553 560	587 590 595	615 619 622	635 638 642	655 657 663	673 675 678	687 689 692	708 712 717	728 732 735	748 750 755	765 765 767	776 778 782	788 792 793	800 803 805	810 813 815
COPPER	STRANDED	1031 998 964		800 000 750 000 700 000	.0139 .0148 .0158	.0735 .0782 .0835		132 136	213 216 221	261 265 268	296 300 305	324 327 332	346 350 354	380 384 388	428 434 436	480 483 486	514 518 522	562 567 570	597 602 605	625 629 633	645 651 655	667 670 675	682 686 690	696 697 703	720 725 728	740 744 745	758 762 765	775 775 780	786 790 792	795 800 805	810 814 815	820 824 826
COPPER	STRANDED	929 893 855		650 000 600 000 550 000	.0170 .0185 .0202	.0900 .0978 .107		141 145 151	225 231 235	275 279 284	308 314 319	336 339 344	358 362 368	392 398 402	442 445 452	492 495 501	525 530 535	575 580 583	609 615 620	638 640 647	659 665 670	678 682 688	695 700 705	708 712 718	732 736 742	752 755 762	770 777 780	785 790 795	800 803 808	810 815 822	822 825 833	833 835 843
COPPER	STRANDED	815 772 728		500 000 450 000 400 000	.0222 .0247 .0277	.117 .131 .147		157 163 170	241 247 255	290 296 304	325 330 338	350 358 364	374 380 388	410 414 423	458 463 472	508 512 520	542 548 555	592 597 605	626 633 640	654 660 667	676 680 688	690 698 709	711 716 722	724 730 738	748 755 762	769 773 782	787 792 800	800 807 814	813 822 828	825 833 840	840 845 852	849 855 860
COPPER	STRANDED	681 630 575		350 000 300 000 250 000	.0316 .0370 .0444	.167 .196 .235		178 187 199	264 273 282	312 320 332	346 356 366	372 382 392	396 403 416	430 437 450	480 488 500	529 537 550	564 573 585	613 620 634	648 657 669	675 682 696	697 706 718	716 725 734	732 740 753	746 756 765	770 780 790	792 798 812	809 815 829	822 832 845	835 845 860	850 860 865	858 868 875	871 880 891
COPPER	STRANDED	528 470 418	0000 000 00	211 600 167 772 133 079	.0525 .0662 .0834	.277 .350 .442	139 153	209 223 237	292 306 320	342 356 370	376 390 403	403 418 432	426 441 454	460 475 488	510 525 539	560 574 588	595 609 622	644 658 672	679 693 707	706 721 734	728 742 756	745 757 772	763 777 791	774 788 802	797 814 827	820 833 846	839 853 867	853 866 880	865 878 895	880 893 908	892 905 919	901 915 929
COPPER	STRANDED	373 332 292	0 1 2	105 560 83 694 66 358	.105 .132 .167	.555 .697 .883	167 181 195	251 265 279	334 348 362	384 399 412	418 432 445	445 460 473	469 483 497	502 515 530	552 567 581	602 616 630	637 651 665	686 700 714	721 735 749	748 762 776	770 784 798	787 800 813	805 819 833	817 832 845	843 855 870	862 875 890	881 895 910	895 910 923	908 925 938	920 935 950	935 950 959	943 957 971
COPPER	STRANDED	260 232 206	3 4 5	52 624 41 738 33 088	.211 .266 .336	1 12 1 41 1 78	209 223 237	292 307 320	377 390 403	425 440 453	460 475 487	488 502 515	510 525 538	543 558 573	594 609 620	643 658 670	677 693 705	727 742 753	760 777 789	787 804 815	810 826 837	828 840 857	845 861 875	860 873 888	885 895 910	903 915 930	922 937 950	940 950 965	952 964 980	965 980 995	978 990 1001	985 999 1013
COPPER	SOLID	460 410 365	0000 000 00	211 600 167 772 133 079	.0514 .0647 .0817	.272 .342 .432	123 139 153	209 223 237	292 306 320	342 356 370	376 390 403	403 418 432	426 441 454	460 475 488	510 525 539	560 574 588	595 609 622	644 658 672	679 693 707	706 720 734	728 742 756	745 757 772	763 777 791	774 788 802	797 814 827	820 833 846	839 853 867	853 866 880	865 878 895	880 893 908	892 905 919	901 915 929
COPPER	SOLID	325 289 258	0 1 2	105 560 83694 66358	.103 .129 .163	.545 .680 .862	167 181 195	251 265 279	334 348 362	384 399 412	418 432 445	445 460 473	469 483 497	502 515 530	552 567 581	602 616 630	637 651 665	686 700 714	721 735 749	748 762 776	770 784 798	787 800 813	805 819 833	817 832 845	843 855 870	862 875 890	881 895 910	895 910 923	908 925 938	920 935 950	935 950 959	943 957 971
COPPER	SOLID	229 204 182	3 4 5	52 624 41 738 33 088	.207 .260 .328	1 10 1 38 1 73	209 223 237	292 307 320	377 390 403	425 440 453	460 475 487	488 502 515	510 525 538	543 558 573	594 609 620	643 658 670	677 693 705	727 742 753	760 777 789	787 804 815	810 826 837	828 840 857	845 861 875	860 873 888	885 895 910	903 915 930	922 937 950	940 950 965	952 964 980	965 980 995	978 990 1001	985 999 1013
ALUMINUM	STEEL REINFORCED	953 904 741		605 000 500 000 336 420	.0291 .0352 .0525	.154 .186 .277		145 157 181	229 240 265	279 288 315	312 324 348	340 354 374	362 374 398	398 410 434	447 458 482	493 507 530	530 541 567	580 591 615	615 627 650	642 655 677	662 676 698	683 692 718	698 710 734	713 725 745	738 745 770	758 768 795	774 785 810	790 802 825	805 815 840	815 825 852	825 839 860	835 852 875
ALUMINUM	STEEL REINFORCED	635 564 501		266 800 211 950 167 800	.0662 .0834 .105	.350 .442 .555		195 209 222	280 292 307	328 340 356	362 378 390	388 402 418	412 427 440	448 460 476	495 510 525	545 560 573	582 595 608	630 643 660	666 676 690	690 707 718	715 726 743	730 747 760	746 762 775	763 775 790	786 795 815	805 816 836	825 840 853	840 855 870	853 870 880	865 879 892	875 890 905	890 902 915
ALUMINUM	STEEL REINFORCED	447 [illegible] 355		133 200 105 530 83 640	.132 [illegible] .211	.697 .883 1 12	152 167 181	236 250 264	321 336 348	370 382 398	406 418 432	430 448 462	454 468 482	490 501 518	540 554 568	588 600 615	623 637 650	671 685 698	705 720 730	735 745 760	755 768 782	774 787 803	790 805 815	805 817 835	830 845 855	850 865 876	865 882 895	885 895 908	895 910 925	908 925 935	918 932 945	930 945 955
ALUMINUM	STEEL REINFORCED	316 281 250		66 370 52 630 41 740	.266 .336 .423	1 41 1 78 2 24	195 209 222	278 292 306	362 376 392	412 424 440	445 460 476	475 488 503	496 510 525	531 545 558	580 595 610	630 645 659	666 678 690	713 725 743	746 763 775	775 790 805	795 810 827	817 830 845	833 845 862	845 862 875	869 885 900	892 905 920	908 925 937	925 938 952	940 950 965	950 965 980	965 975 990	970 985 993

A	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175	180	185	190	195	200
B	006	011	017	022	027	032	.036	040	045	049	053	057	061	065	068	072	075	078	081	084

x The reactance for any distance D not given in the table can be found as follows: Let E = the nearest smaller distance in the table. Divide D by E and taking a value of A nearest to the quotient find the corresponding value of B, which must be added to the reactance corresponding to the size of conductor and distance E.

For three-phase regular flat spacing use D = 1.26 A. For three-phase irregular flat or triangular spacing use $D = \sqrt[3]{A\,B\,C}$. For a two-phase line the spacing is the average distance between centers of conductors of the same phase.

xx At a temperature of 65° C (149° F) these resistance values would be increased by 15 percent. They are based upon a conductivity for copper of 97.3—for aluminum of 61 percent. They do not take into account skin effect: this should be considered when the larger conductors are used, particularly at the higher frequencies. No allowance has been made for increased length due to sag when the conductors are two percent greater than for a solid rod of cross section equal to the total cross section of the wires of the cable.

For stranded conductors D was taken as the diameter of a solid rod of equivalent cross sectional area. Actually D for stranded conductors is slightly greater, resulting in slightly less reactance than the table values. The table values are therefore conservative. In calculating the reactance values for the steel reinforced aluminum cable the presence of the steel strands was ignored.

TABLE VI RATIO OF 25 CYCLE REACTANCE TO RESISTANCE AT 25° C

THE RESISTANCE VOLTS HAVING BEEN DETERMINED (AT 25° C) THE REACTANCE VOLTS MAY BE FOUND BY MULTIPLYING THE RESISTANCE VOLTS BY THE CONSTANTS GIVEN IN TABLE BELOW FOR THE SPACING AND SIZE OF CONDUCTORS CONTEMPLATED. THE RATIO FOR OTHER FREQUENCIES IS $\frac{F}{25}$ TIMES THE TABLE VALUES. FOR A TEMPERATURE OF 65° C (149° F) MULTIPLY TABLE VALUES BY .87

CONDUCTORS; RESISTANCE OF A SINGLE CONDUCTOR IN OHMS AT 25° C (77° F) xx; DISTANCE (D) BETWEEN CENTERS OF CONDUCTORS x

Material	Type	Diameter in Inches	B & S No	Area in Circular Mils	Per 1000 Feet	Per Mile	1/2"	1"	2"	3"	4"	5"	6"	8"	12"	18"
COPPER	STRANDED	1631		2 000 000	00054	0293			222	293	342	382	412	460	532	598
		1548		1 800 000	[illegible]	0323			209	274	317	350	379	425	486	547
		1504		1 700 000	00652	0344			202	262	302	334	364	404	463	524
		1459		1 600 000	00693	[illegible]			194	248	289	319	346	384	438	493
		1412		1 500 000	00739	[illegible]			187	238	276	304	327	363	[illegible]	468
		1364		1 400 000	00792	[illegible]			177	227	260	287	308	344	392	442
		1263		1 200 000	00924	0489			160	202	231	254	272	302	344	385
		1209		1 100 000	0101	0533			150	187	215	238	255	281	320	356
		1152		1 000 000	0111	0587			142	178	200	220	236	260	295	331
		1123		950 000	0117	0618			136	170	191	210	225	249	283	316
		1093		900 000	0123	0650			132	163	185	203	217	238	271	302
		1062		850 000	0130	0688			126	157	177	195	208	228	257	286
		1031		800 000	0139	0735			121	148	169	184	196	215	242	272
		998		750 000	0148	0782		70	115	141	160	174	187	205	232	257
		964		700 000	0158	0835		68	110	134	152	165	177	193	218	242
		929		650 000	0170	0900		66	104	127	143	156	166	181	204	228
		893		600 000	0185	0978		62	98	119	134	144	155	170	190	211
		855		550 000	0202	107		59	92	110	124	134	143	156	176	194
		815		500 000	0222	117		56	85	103	115	125	133	146	163	181
		772		450 000	0247	131		52	79	95	105	114	121	132	147	163
		728		400 000	0277	147		48	72	86	96	103	110	120	133	147
		.681		350 000	0316	[illegible]		44	66	78	86	93	99	107	120	132
		.630		300 000	0370	196		40	58	68	76	81	86	93	104	115
		.575		250 000	0444	233		35	50	59	65	69	74	80	89	97
		528	0000	211 600	0525	[illegible]		31	44	51	57	61	64	69	77	84
		470	000	167 772	0662	350	16	26	37	42	46	50	52	56	62	68
		418	00	133 079	0834	442	14	22	30	35	38	41	43	46	51	55
		373	0	105 560	[illegible]	[illegible]	12	19	25	29	31	33	35	38	41	45
		332	1	83 694	132	[illegible]	11	16	21	24	26	28	29	31	34	37
		292	2	66 358	167	883	09	13	17	19	21	22	24	25	27	30
		260	3	52 624	[illegible]	[illegible]	08	11	14	16	17	18	19	20	.22	24
		232	4	41 738	266	141	06	09	11	13	14	15	15	16	.18	19
		206	5	33 088	336	178	05	07	09	10	11	12	12	13	14	16
	SOLID	.460	0000	211 600	0514	272	19	32	45	52	58	62	65	71	78	86
		.410	000	167 772	0647	342	17	26	37	43	48	51	54	58	64	70
		.365	00	133 079	0817	432	14	23	31	36	39	42	44	47	.52	57
		.325	0	105 560	103	545	13	19	25	29	32	34	36	38	42	46
		.289	1	83 694	[illegible]	680	10	16	21	24	26	28	29	.31	35	38
		.258	2	66 358	163	862	09	13	17	20	22	23	24	25	28	30
		.229	3	52 624	207	[illegible]	08	11	14	16	17	18	19	20	22	24
		.204	4	41 738	260	138	07	09	12	13	14	15	16	17	18	.20
		182	5	33 088	328	[illegible]	06	08	09	11	13	12	13	14	15	16
ALUMINUM	STEEL REINFORCED	953		605 000	[illegible]	154		39	62	75	85	92	98	108	120	133
		904		500 000	0352	186		35	54	.62	70	79	81	92	102	113
		741		336 420	0525	277		27	40	47	52	56	60	65	72	.80
		635		266 800	0662	350		23	33	39	43	46	49	53	59	65
		564		211 950	0834	442		20	28	32	35	38	40	43	48	.52
		501		167 800	105	[illegible]		17	23	27	30	31	33	36	40	43
		447		133 200	132	[illegible]	09	14	19	22	24	26	27	26	32	35
		.398		105 530	167	883	08	12	16	18	20	21	22	24	26	.28
		.355		83 640	211	[illegible]	07	10	13	15	16	17	18	19	21	22
		316		66 370	266	141	06	08	11	12	13	14	15	16	17	18
		281		52 630	336	178	05	07	09	10	11	11	12	12	13	15
		.250		41 740	423	224	04	06	07	08	09	09	10	.10	11	.12

Material	Type	Diameter in Inches	2 Feet	3 Feet	4 Feet	5 Feet	6 Feet	7 Feet	8 Feet	9 Feet	11 Feet	13 Feet	15 Feet	17 Feet	19 Feet	21 Feet	23 Feet	25 Feet
COPPER	STRANDED	1631	652	720	768	800	835	867	892	908	945	973	995	1020	1040	1050	1070	1080
		1548	595	660	702	740	764	788	806	830	860	883	905	927	942	960	[illegible]	985
		1504	567	625	670	702	727	753	770	785	817	840	860	878	895	[illegible]	922	934
		1459	535	590	630	[illegible]	685	[illegible]	725	742	769	790	810	830	843	860	870	883
		1412	505	[illegible]	596	624	648	668	683	700	725	748	765	782	797	810	825	832
		1364	477	[illegible]	560	588	610	630	643	660	680	702	720	734	750	760	772	780
		1263	418	458	487	[illegible]	532	545	560	573	593	608	625	639	650	660	670	675
		1209	385	424	450	475	490	503	517	530	546	562	575	589	598	610	615	625
		1152	355	391	416	430	448	463	476	486	502	515	530	537	550	556	562	573
		1123	338	370	396	414	427	440	453	462	477	490	505	515	525	530	537	545
		1093	325	354	379	397	408	420	432	440	455	470	480	490	497	508	515	520
		1062	308	339	360	375	389	401	410	420	433	445	456	465	472	480	487	495
		1031	291	317	338	354	365	377	381	395	408	419	428	438	445	452	458	465
		998	277	302	321	336	347	357	366	373	385	397	408	415	420	427	435	440
		964	260	285	302	316	327	336	344	350	363	373	382	389	397	402	407	413
		929	242	266	283	296	304	314	322	327	338	348	356	364	370	375	380	385
		893	225	247	262	272	282	290	298	303	313	322	330	337	342	348	352	356
		855	208	227	241	251	262	268	274	280	289	296	304	310	315	320	324	328
		815	193	212	223	233	242	246	253	258	267	273	280	285	290	295	299	302
		772	175	190	201	209	216	222	228	232	241	248	251	257	261	265	269	272
		728	157	172	181	189	195	201	205	204	216	222	226	231	235	238	241	244
		.681	141	153	162	168	175	180	183	187	192	198	202	205	209	212	215	218
		.630	122	132	140	145	150	54	157	161	165	170	173	177	180	183	185	187
		.575	104	112	119	123	127	130	134	135	140	144	147	150	152	153	156	158
		528	90	97	102	106	109	112	115	116	120	123	126	128	130	132	134	136
		470	73	79	83	86	88	90	93	94	97	99	102	103	105	107	108	109
		418	59	63	66	69	71	73	75	76	78	80	82	83	84	86	87	88
		373	48	51	54	56	58	59	60	61	63	65	66	67	68	69	70	71
		332	39	42	44	46	47	48	49	50	51	52	54	55	55	56	57	57
		292	31	34	35	36	38	38	39	40	41	42	43	43	44	44	45	46
		260	25	27	28	29	30	31	31	32	33	33	34	35	35	36	36	37
		232	20	22	23	24	24	25	25	26	26	27	28	28	28	29	29	30
		206	16	18	18	19	19	20	20	21	21	22	22	23	23	23	23	24
	SOLID	.460	91	99	104	108	112	114	117	119	121	125	129	131	132	135	136	138
		.410	74	80	84	88	90	92	95	96	.99	102	104	106	107	109	110	112
		.365	60	65	68	71	73	74	76	77	80	82	84	85	86	88	89	90
		.325	49	52	55	57	59	60	62	63	64	66	67	68	69	71	71	72
		.289	40	43	45	47	48	49	50	51	52	53	55	56	56	58	58	59
		.258	32	35	36	37	39	39	40	41	42	43	44	44	45	46	46	47
		.229	25	27	29	30	31	31	32	32	33	34	35	35	36	36	37	37
		.204	21	22	23	24	25	25	26	26	27	28	28	29	29	29	30	30
		182	17	18	19	20	20	21	21	21	22	22	23	23	24	24	24	24
ALUMINUM	STEEL REINFORCED	953	143	156	166	173	180	185	189	192	200	205	209	213	218	221	224	227
		904	122	132	140	146	152	155	159	162	167	172	176	180	183	185	188	191
		741	85	.92	98	102	105	108	110	112	116	119	122	124	126	128	129	131
		635	69	75	80	82	85	87	89	91	93	96	98	100	102	103	104	106
		564	56	60	63	66	68	70	71	73	75	77	79	80	82	83	84	85
		501	45	50	.51	54	56	57	58	59	61	63	64	65	66	67	68	69
		447	37	40	42	44	45	46	47	48	50	51	52	53	54	54	55	55
		.398	30	32	34	35	36	37	38	39	40	41	41	42	43	44	44	45
		.355	24	26	27	28	29	30	30	31	32	32	33	34	34	35	35	35
		316	20	21	22	23	24	24	25	25	26	26	27	27	28	28	29	29
		281	16	17	.18	18	19	19	19	20	21	21	21	22	22	22	23	23
		.250	13	.14	14	15	15	.6	16	16	17	17	17	18	18	18	18	19

x For three phase regular flat spacing use D = 1.26 A. For three-phase irregular flat or triangular spacing use $D = \sqrt[3]{ABC}$. For a two phase line the spacing is the average distance between centers of conductors of the same phase.

xx At a temperature of 65° C (149° F) these resistance values would be increased by 15 percent. They are based upon a conductivity for copper of 97.3, for aluminum of 61 percent. They do not take into account skin effect; this should be considered when the larger conductors are used, particularly at the higher frequencies. No allowance has been made for increased length due to sag when the conductors are suspended. The resistance values for the stranded conductors are two percent greater than for a solid rod of cross section equal to the total cross section of the wires of the cable.

For stranded conductors D was taken as the diameter of a solid rod of equivalent cross sectional area. Actually D for stranded conductors is slightly greater resulting in slightly less reactance than the table values. The table values are therefore conservative. In calculating the reactance values for the steel reinforced aluminum cable the presence of the steel strands was ignored.

TABLE VII—RATIO OF 60 CYCLE REACTANCE TO RESISTANCE AT 25° C

THE RESISTANCE VOLTS HAVING BEEN DETERMINED (AT 25° C) THE REACTANCE VOLTS MAY BE FOUND BY MULTIPLYING THE RESISTANCE VOLTS BY THE CONSTANTS GIVEN IN TABLE BELOW FOR THE SPACING AND SIZE OF CONDUCTORS CONTEMPLATED. THE RATIO FOR OTHER FREQUENCIES ~~IS~~ $\frac{F}{60}$ TIMES THE TABLE VALUES FOR A TEMPERATURE OF 65° C (149° F) MULTIPLY TABLE VALUES BY 87

CONDUCTORS					RESISTANCE OF A SINGLE CONDUCTOR IN OHMS AT 25 C (77° F) XX		DISTANCE (D) BETWEEN CENTERS OF CONDUCTORS X																									
MATERIAL	TYPE	DIAMETER IN INCHES	B & S NO.	AREA IN CIRCULAR MILS	PER 1000 FEET	PER MILE	1/2"	1"	2"	3"	4"	5"	6"	8"	12"	18"	2 FEET	3 FEET	4 FEET	5 FEET	6 FEET	7 FEET	8 FEET	9 FEET	11 FEET	13 FEET	15 FEET	17 FEET	19 FEET	21 FEET	23 FEET	25 FEET
COPPER	STRANDED	1631		2 000 000	.00554	0293			536	707	823	916	990	1110	1280	144	157	173	185	192	201	208	214	219	227	234	239	246	250	253	258	260
		1548		1 800 000	.00615	0320			502	652	758	846	915	1020	1170	132	143	158	170	177	184	190	194	200	207	213	218	223	[illegible]	231	234	237
		1504		1 700 000	.00652	0344			483	630	730	805	872	970	1120	126	136	150	161	169	174	180	185	189	196	202	206	211	215	219	222	225
		1459		1 600 000	00693	0367			463	597	696	767	830	922	1060	119	129	142	152	160	164	170	175	174	185	190	195	200	202	207	209	212
		1412		1 500 000	00739	.0391			445	570	662	725	790	875	995	113	121	134	143	150	156	160	164	168	175	180	184	185	191	194	197	199
		1364		1 400 000	00792	0418			423	540	626	690	740	828	943	106	115	126	135	141	147	152	[illegible]	159	164	169	173	176	180	183	185	188
		1263		1 200 000	00924	0489			382	484	552	610	655	728	826	920	100	110	117	122	128	131	134	137	142	146	150	153	156	158	161	162
		1209		1 100 000	0101	0533			360	451	520	570	611	675	770	860	925	102	108	114	118	121	124	127	131	[illegible]	139	141	144	146	148	151
		1152		1 000 000	0111	0587			340	422	481	529	565	625	710	792	852	937	996	104	108	111	114	117	121	124	127	129	132	134	135	138
		1123		950 000	0117	0618			325	405	460	505	542	600	680	755	812	895	950	995	103	106	109	111	114	118	121	124	125	127	129	131
		1093		900 000	0123	0650			315	392	443	487	520	575	650	724	782	850	910	952	982	101	104	106	109	113	115	118	120	122	124	125
		1062		850 000	0130	0688			304	376	424	465	497	546	620	690	740	815	865	903	933	965	985	100	104	107	110	111	113	115	117	118
		1031		800 000	0139	0735			290	355	403	442	470	517	583	655	700	765	815	850	880	910	930	950	980	[illegible]	103	106	107	108	110	112
		998		750 000	0148	0782		169	276	339	384	418	448	491	555	618	663	725	770	805	835	860	878	892	928	[illegible]	975	992	101	102	104	105
		964		700 000	0158	0835		163	265	321	366	398	425	465	523	582	625	683	725	760	785	810	827	843	872	[illegible]	917	935	950	[illegible]	977	990
		929		650 000	0170	0900		156	250	306	342	373	398	435	490	546	585	640	677	710	732	755	773	788	815	835	855	873	890	900	915	928
		893		600 000	0185	0978		148	236	285	321	347	370	407	455	505	542	593	630	655	680	698	715	727	752	772	795	808	820	835	845	855
		855		550 000	0202	107		141	220	266	298	322	344	376	422	468	500	545	580	605	627	645	660	672	695	712	730	745	757	770	780	790
		815		500 000	0222	117		134	206	248	278	299	320	351	392	435	463	505	533	560	578	590	608	620	640	658	673	685	696	705	718	725
		772		450 000	0247	131		124	188	226	252	274	290	316	354	390	418	455	484	504	520	532	547	558	577	590	605	615	628	635	645	655
		728		400 000	0277	147		116	174	207	230	248	264	288	321	354	377	412	435	455	468	482	491	502	518	532	545	555	563	572	580	585
		.681		350 000	0316	167		106	158	187	208	223	237	258	287	317	338	368	388	405	417	430	439	447	462	475	485	492	500	510	515	522
		630		300 000	0370	196		96	140	163	181	195	206	223	249	274	292	316	334	348	360	370	377	386	398	408	417	425	432	440	444	450
		575		250 000	0444	235		85	120	141	156	167	176	191	213	234	250	270	285	297	306	313	320	326	336	346	353	360	366	368	372	380
		528	0000	211 600	0525	277		76	105	123	136	146	154	166	184	202	215	233	246	255	263	269	276	280	288	297	303	308	313	318	322	326
		470	000	167 772	0662	350	40	64	87	102	111	120	126	136	150	164	174	188	198	206	212	216	222	[illegible]	233	238	244	247	251	256	260	262
		418	00	133 079	0834	442	34	54	72	84	91	98	103	111	122	133	141	152	160	166	171	175	[illegible]	181	187	192	196	200	203	206	208	210
		373	0	105 560	105	555	30	45	60	69	75	80	84	90	100	108	115	123	130	135	139	142	145	147	152	155	159	161	164	166	168	170
		332	1	83 694	132	697	26	38	50	57	62	66	70	74	81	88	94	100	106	110	113	[illegible]	[illegible]	120	[illegible]	126	128	131	133	134	136	138
		292	2	66 358	167	883	22	32	41	47	50	53	56	60	65	71	75	81	85	88	90	[illegible]	[illegible]	96	[illegible]	[illegible]	103	105	106	108	108	110
		260	3	52 624	211	112	19	26	34	38	41	44	45	48	53	58	60	65	68	70	72	74	75	77	79	81	82	84	85	86	87	88
		.232	4	41 738	266	141	16	22	28	31	34	35	37	40	43	47	49	53	55	57	59	60	61	62	63	65	66	67	68	69	70	71
		206	5	33 088	336	178	13	18	22	25	27	29	30	32	35	37	40	42	44	46	47	48	49	50	51	52	53	54	55	56	56	57
	SOLID †	460	0000	211 600	0514	272	45	76	106	125	138	148	156	169	187	206	218	237	250	260	268	272	281	284	293	302	308	313	318	324	328	331
		410	000	167 772	0647	342	40	65	90	104	114	122	129	139	153	168	178	192	204	210	217	220	227	230	238	243	250	253	257	262	266	268
		365	00	133 079	0817	432	35	55	73	85	94	100	105	113	125	136	144	155	164	170	175	179	184	186	191	196	200	204	208	201	213	215
		325	0	105 560	.103	545	31	46	61	70	77	82	86	92	101	111	117	126	132	137	141	145	148	150	155	158	161	164	166	169	171	173
		289	1	83 694	129	680	26	39	51	59	63	67	71	76	83	90	95	103	108	112	115	117	120	122	126	128	132	134	136	138	140	141
		258	2	66 358	.163	862	22	32	42	48	52	55	57	61	67	73	77	83	87	89	92	94	96	98	101	103	105	107	109	110	111	112
		229	3	52 624	207	110	19	26	34	39	42	44	46	49	54	58	61	66	69	71	74	75	77	78	80	82	84	86	87	88	88	90
		.204	4	41 738	260	138	16	22	28	32	34	36	38	40	44	48	50	53	56	58	60	61	62	63	65	66	68	69	70	71	72	72
		182	5	33 088	328	173	14	18	23	26	28	30	31	33	.36	39	40	43	45	47	48	50	50	51	52	54	55	56	57	57	58	58
ALUMINUM	STEEL REINFORCED	953		605 000	029	154		94	149	180	202	220	234	258	290	320	344	377	400	417	430	442	453	464	478	492	502	512	522	530	536	542
		904		500 000	0352	186		84	129	155	175	190	201	221	247	273	290	318	338	353	364	372	382	390	400	413	423	432	438	445	452	460
		741		336 420	0525	277		65	95	114	125	135	144	157	174	191	204	222	235	245	252	259	266	270	278	287	293	298	303	308	310	316
		635		266 800	0662	350		55	80	94	103	110	117	128	141	156	166	180	190	197	204	208	212	218	224	230	235	240	243	247	250	254
		564		211 950	0834	442		47	66	77	85	91	97	104	115	126	135	145	153	160	164	169	172	175	180	185	190	194	197	200	202	204
		501		167 800	100	555		40	55	64	70	75	79	85	95	103	110	119	124	130	134	137	140	143	147	150	154	157	159	161	163	165
		447		133 200	132	697	22	34	46	53	58	62	65	70	77	84	89	96	101	105	108	[illegible]	113	116	119	122	124	126	128	130	132	134
		398		105 530	[illegible]	883	19	28	38	43	47	50	53	56	62	68	72	77	82	84	87	89	91	92	95	98	100	101	103	105	105	107
		355		83 640	211	112	16	24	31	35	39	41	43	46	50	55	58	62	65	68	70	72	73	74	76	78	80	81	82	83	84	85
		316		66 370	266	141	14	20	25	29	31	34	35	37	41	45	47	50	52	53	56	58	59	60	61	63	64	65	67	67	69	69
		281		52 630	335	178	11	16	21	24	26	27	28	30	33	36	38	40	43	44	45	46	47	48	50	50	52	52	53	54	54	55
		250		41 740	423	224	10	13	17	19	21	22	23	25	27	29	31	33	34	36	37	38	39	39	40	40	42	42	43	44	44	45

For three phase regular flat spacing use D = 1.26 A. For three-phase irregular flat or triangular spacing use $D = \sqrt[3]{ABC}$. For a two phase line the spacing is the average distance between centers of conductors of the same phase.

xx At a temperature of 65° C (149° F) these resistance values would be increased by 15 percent. They are based upon a conductivity for copper of 97.3 for aluminum of 61 percent. They do not take into account skin effect; this should be considered when the larger conductors are used, particularly at the higher frequencies. No allowance has been made for increased length due to sag when the conductors are suspended. The resistance values for the stranded conductors are two percent greater than for a solid rod of cross section equal to the total cross section of the wires of the cable.

For stranded conductors D was taken as the diameter of a solid rod of equivalent cross sectional area. Actually D for stranded conductors is slightly greater, resulting in slightly less reactance than the table values. The table values are therefore conservative. In calculating the reactance values for the steel reinforced aluminum cable the presence of the steel strands was ignored.

TABLE VIII—CAPACITANCE TO NEUTRAL PER 1000 FEET OF SINGLE BARE CONDUCTOR

CAPACITANCE (C) TO NEUTRAL IN MICROFARADS PER 1000 FEET OF EACH CONDUCTOR OF A SINGLE-PHASE OR OF A SYMMETRICAL THREE-PHASE LINE. THE VALUES FOR CAPACITANCE WERE DERIVED FROM THE EQUATION $C = \dfrac{.007354}{\log_{10}\left[\dfrac{D}{2R}+\left(\left(\dfrac{D}{2R}\right)^2-1\right)^{\frac{1}{2}}\right]}$ R BEING THE RADIUS OF THE CONDUCTOR EXPRESSED IN SAME TERMS AS D. X X THE CAPACITANCE BETWEEN CONDUCTORS EQUALS ONE HALF THE TABLE VALUES

CONDUCTORS					DISTANCE (D) BETWEEN CENTERS OF CONDUCTORS X																									
MATERIAL	TYPE	DIAMETER IN INCHES	B & S NO.	AREA IN CIRCULAR MILS	1/2"	1"	2"		4"	5"	6"	8"	12"	18"	2 FEET	3 FEET	4 FEET	5 FEET	6 FEET	7 FEET	8 FEET	9 FEET	11 FEET	13 FEET	15 FEET	17 FEET	19 FEET	21 FEET	23 FEET	25 FEET
COPPER	STRANDED	1.631		2 000 000			.0257	.0139	.0111	.00953	.00857	.00745	.00630	.00547	.00501	.00447	.00418	.00396	.00378	.00366	.00356	.00346	.00332	.00322	.00314	.00306	.00300	.00294	.00290	.00286
		1.548		1 800 000			.0228	.0132	.0106	.00920	.00835	.00728	.00618	.00538	.00493	.00442	.00412	.00392	.00372	.00362	.00352	.00342	.00330	.00320	.00310	.00304	.00298	.00294	.00288	.00284
		1.504		1 700 000			.0214	.0129	.0104	.00905	.00822	.00718	.00613	.00535	.00490	.00438	.00408	.00388	.00370	.00360	.00348	.00340	.00328	.00318	.00310	.00302	.00296	.00292	.00288	.00284
		1.459		1 600 000			.0203	.0126	.0102	.00890	.00810	.00707	.00605	.00532	.00488	.00435	.00406	.00386	.00370	.00358	.00346	.00338	.00326	.00316	.00308	.00300	.00296	.00290	.00286	.00284
		1.412		1 500 000			.0192	.0123	.00995	.00872	.00796	.00700	.00600	.00528	.00480	.00430	.00404	.00384	.00368	.00354	.00344	.00336	.00324	.00314	.00306	.00300	.00294	.00288	.00284	.00280
		1.364		1 400 000			.0182	.0119	.00972	.00858	.00783	.00690	.00590	.00518	.00475	.00427	.00400	.00380	.00362	.00352	.00342	.00334	.00322	.00312	.00304	.00296	.00290	.00286	.00282	.00278
		1.263		1 200 000			.0164	.0112	.00932	.00825	.00755	.00668	.00577	.00507	.00465	.00418	.00394	.00374	.00356	.00346	.00338	.00330	.00316	.00308	.00300	.00294	.00288	.00284	.00280	.00274
		1.209		1 100 000			.0155	.0109	.00907	.00808	.00740	.00657	.00572	.00500	.00460	.00415	.00390	.00368	.00354	.00344	.00336	.00326	.00314	.00306	.00298	.00290	.00286	.00280	.00278	.00274
		1.152		1 000 000			.0147	.0105	.00883	.00790	.00725	.00645	.00558	.00492	.00454	.00410	.00383	.00365	.00351	.00340	.00331	.00324	.00312	.00302	.00295	.00288	.00282	.00280	.00274	.00271
		1.123		950 000			.0143	.0104	.00872	.00778	.00717	.00638	.00552	.00488	.00450	.00407	.00382	.00362	.00348	.00338	.00330	.00322	.00310	.00302	.00294	.00288	.00282	.00278	.00274	.00270
		1.093		900 000			.0140	.0102	.00858	.00770	.00710	.00632	.00548	.00483	.00448	.00403	.00380	.00360	.00346	.00336	.00328	.00320	.00308	.00298	.00292	.00286	.00280	.00276	.00272	.00268
		1.062		850 000			.0136	.0100	.00845	.00760	.00700	.00623	.00545	.00480	.00445	.00402	.00378	.00358	.00344	.00334	.00326	.00318	.00306	.00298	.00290	.00284	.00280	.00276	.00270	.00268
		1.031		800 000			.0132	.00978	.00832	.00750	.00693	.00618	.00536	.00477	.00440	.00399	.00374	.00354	.00342	.00332	.00324	.00316	.00306	.00296	.00290	.00284	.00278	.00274	.00270	.00266
		.998		750 000			.0126	.00958	.00820	.00738	.00683	.00612	.00533	.00472	.00437	.00396	.00371	.00353	.00341	.00330	.00322	.00316	.00304	.00296	.00288	.00282	.00278	.00272	.00268	.00265
		.964		700 000		.0618	.0125	.00942	.00807	.00727	.00672	.00602	.00530	.00468	.00435	.00393	.00370	.00352	.00338	.00328	.00320	.00312	.00302	.00292	.00286	.00280	.00274	.00270	.00266	.00264
		.929		650 000		.0432	.0120	.00920	.00792	.00715	.00663	.00597	.00522	.00462	.00430	.00389	.00366	.00348	.00336	.00326	.00318	.00312	.00300	.00292	.00284	.00278	.00274	.00270	.00266	.00262
		.893		600 000		.0300	.0117	.00900	.00777	.00703	.00652	.00588	.00515	.00458	.00425	.00386	.00362	.00346	.00334	.00324	.00316	.00308	.00298	.00290	.00282	.00276	.00272	.00268	.00264	.00260
		.855		550 000		.0295	.0113	.00877	.00761	.00690	.00643	.00578	.00507	.00454	.00420	.00381	.00358	.00342	.00330	.00322	.00312	.00306	.00296	.00286	.00280	.00274	.00270	.00266	.00262	.00260
		.813		500 000		.0255	.0109	.00856	.00745	.00675	.00630	.00570	.00501	.00447	.00415	.00378	.00355	.00339	.00327	.00318	.00310	.00304	.00297	.00284	.00278	.00274	.00268	.00264	.00260	.00257
		.772		450 000		.0224	.0105	.00832	.00727	.00662	.00618	.00560	.00493	.00440	.00411	.00373	.00352	.00336	.00324	.00314	.00306	.00300	.00290	.00282	.00276	.00270	.00266	.00260	.00258	.00254
		.728		400 000		.0202	.0101	.00808	.00706	.00648	.00608	.00548	.00483	.00435	.00403	.00369	.00348	.00332	.00320	.00312	.00304	.00298	.00288	.00280	.00272	.00268	.00264	.00260	.00256	.00252
		.681		350 000		.0181	.00974	.00783	.00688	.00631	.00591	.00537	.00476	.00427	.00398	.00363	.00342	.00328	.00316	.00308	.00300	.00294	.00284	.00276	.00270	.00264	.00260	.00258	.00252	.00250
		.630		300 000		.0164	.00930	.00753	.00663	.00612	.00575	.00523	.00465	.00418	.00391	.00357	.00338	.00322	.00312	.00304	.00296	.00290	.00280	.00272	.00266	.00262	.00256	.00254	.00250	.00246
		.575		250 000		.0147	.00883	.00725	.00645	.00595	.00558	.00511	.00454	.00409	.00383	.00351	.00331	.00317	.00307	.00298	.00292	.00286	.00276	.00268	.00263	.00258	.00254	.00250	.00246	.00244
		.528	0000	211 600		.0136	.00843	.00700	.00623	.00574	.00542	.00497	.00444	.00401	.00376	.00345	.00326	.00312	.00302	.00294	.00287	.00282	.00272	.00266	.00260	.00256	.00250	.00246	.00244	.00240
		.470	000	167 772	.0477	.0122	.00795	.00667	.00598	.00557	.00523	.00480	.00431	.00390	.00366	.00337	.00318	.00306	.00296	.00288	.00282	.00276	.00268	.00260	.00255	.00250	.00246	.00242	.00240	.00237
		.418	00	133 079	.0275	.0112	.00755	.00637	.00575	.00532	.00504	.00466	.00418	.00380	.00357	.00329	.00312	.00299	.00290	.00282	.00276	.00272	.00262	.00256	.00251	.00246	.00242	.00238	.00236	.00233
		.373	0	105 560	.0213	.0103	.00716	.00610	.00552	.00518	.00488	.00451	.00407	.00371	.00349	.00322	.00305	.00293	.00284	.00278	.00271	.00266	.00258	.00252	.00247	.00242	.00238	.00234	.00232	.00229
		.332	1	83 694	.0175	.00960	.00682	.00586	.00532	.00497	.00472	.00438	.00396	.00361	.00341	.00315	.00299	.00288	.00279	.00272	.00266	.00260	.00254	.00246	.00242	.00238	.00234	.00232	.00228	.00226
		.292	2	66 358	.0150	.00890	.00648	.00560	.00512	.00480	.00456	.00422	.00384	.00352	.00332	.00308	.00292	.00281	.00273	.00266	.00261	.00256	.00248	.00242	.00238	.00234	.00230	.00228	.00226	.00222
		.260	3	52 624	.0133	.00857	.00622	.00538	.00495	.00465	.00442	.00410	.00376	.00344	.00326	.00302	.00286	.00276	.00268	.00262	.00256	.00252	.00244	.00238	.00234	.00230	.00226	.00224	.00222	.00218
		.232	4	41 738	.0121	.00792	.00596	.00521	.00478	.00451	.00429	.00400	.00365	.00336	.00318	.00295	.00281	.00271	.00263	.00256	.00252	.00248	.00240	.00234	.00230	.00226	.00224	.00220	.00218	.00215
		.206	5	33 088	.0111	.00746	.00572	.00503	.00463	.00438	.00417	.00390	.00356	.00328	.00312	.00288	.00276	.00266	.00260	.00252	.00248	.00244	.00236	.00232	.00226	.00224	.00220	.00218	.00214	.00212
	SOLID	.460	0000	211 600	.0412	.0120	.00788	.00654	.00593	.00552	.00519	.00477	.00428	.00388	.00364	.00335	.00317	.00304	.00295	.00288	.00281	.00276	.00266	.00260	.00254	.00248	.00246	.00242	.00238	.00236
		.410	000	167 772	.0260	.0110	.00747	.00632	.00570	.00532	.00501	.00462	.00416	.00378	.00356	.00328	.00310	.00298	.00289	.00282	.00275	.00270	.00262	.00256	.00250	.00244	.00242	.00238	.00234	.00232
		.365	00	133 079	.0203	.0102	.00710	.00605	.00550	.00510	.00485	.00448	.00405	.00369	.00347	.00320	.00304	.00292	.00283	.00276	.00270	.00266	.00258	.00250	.00246	.00240	.00236	.00234	.00230	.00229
		.325	0	105 560	.0170	.00946	.00675	.00582	.00528	.00493	.00469	.00435	.00394	.00360	.00339	.00314	.00298	.00286	.00278	.00270	.00265	.00260	.00252	.00246	.00242	.00236	.00234	.00230	.00228	.00225
		.289	1	83 694	.0148	.00886	.00647	.00558	.00510	.00477	.00455	.00422	.00383	.00351	.00331	.00307	.00292	.00281	.00273	.00266	.00261	.00256	.00248	.00242	.00238	.00232	.00230	.00226	.00224	.00222
		.258	2	66 358	.0132	.00835	.00620	.00538	.00493	.00462	.00441	.00410	.00374	.00343	.00324	.00301	.00286	.00276	.00268	.00262	.00256	.00252	.00244	.00238	.00234	.00230	.00226	.00222	.00220	.00218
		.229	3	52 624	.0120	.00787	.00592	.00520	.00477	.00448	.00427	.00400	.00364	.00336	.00318	.00294	.00280	.00270	.00262	.00256	.00252	.00248	.00240	.00234	.00230	.00226	.00222	.00220	.00218	.00214
		.204	4	41 738	.0110	.00745	.00570	.00500	.00462	.00435	.00416	.00389	.00355	.00327	.00310	.00289	.00275	.00266	.00258	.00252	.00247	.00244	.00236	.00232	.00227	.00222	.00220	.00216	.00214	.00212
		.182	5	33 088	.0102	.00708	.00548	.00485	.00448	.00423	.00403	.00379	.00348	.00320	.00304	.00284	.00270	.00260	.00254	.00248	.00244	.00240	.00232	.00228	.00222	.00220	.00216	.00212	.00212	.00208
ALUMINUM	STEEL REINFORCED	.953		605 000		.0538	.0124	.00932	.00800	.00723	.00675	.00602	.00523	.00466	.00433	.00391	.00368	.00350	.00336	.00326	.00320	.00312	.00302	.00294	.00286	.00280	.00274	.00270	.00266	.00262
		.904		500 000		.0371	.0118	.00912	.00780	.00705	.00657	.00588	.00518	.00460	.00427	.00386	.00364	.00346	.00334	.00324	.00316	.00310	.00299	.00290	.00282	.00278	.00272	.00264	.00264	.00260
		.741		336 420		.0207	.0102	.00817	.00714	.00652	.00610	.00553	.00488	.00435	.00406	.00370	.00348	.00332	.00320	.00312	.00304	.00298	.00288	.00280	.00274	.00270	.00264	.00260	.00256	.00254
		.636		266 800		.0165	.00935	.00757	.00668	.00615	.00580	.00525	.00465	.00420	.00391	.00359	.00336	.00322	.00312	.00304	.00296	.00290	.00280	.00274	.00266	.00262	.00258	.00254	.00250	.00248
		.564		211 950		.0144	.00874	.00717	.00640	.00590	.00552	.00507	.00451	.00407	.00381	.00349	.00330	.00318	.00306	.00296	.00290	.00284	.00276	.00268	.00262	.00258	.00252	.00250	.00246	.00244
		.501		167 800		.0129	.00822	.00682	.00612	.00565	.00533	.00488	.00437	.00395	.00371	.00340	.00322	.00310	.00300	.00292	.00284	.00280	.00270	.00264	.00258	.00252	.00248	.00246	.00242	.00238
		.447		133 200	.0348	.0118	.00778	.00654	.00588	.00545	.00521	.00475	.00425	.00385	.00362	.00334	.00316	.00302	.00294	.00286	.00280	.00274	.00266	.00260	.00252	.00248	.00246	.00242	.00238	.00236
		.398		105 530	.0240	.0108	.00738	.00625	.00565	.00525	.00497	.00458	.00413	.00376	.00354	.00326	.00310	.00296	.00288	.00280	.00274	.00268	.00260	.00254	.00248	.00244	.00242	.00238	.00234	.00232
		.355		83 640	.0193	.00997	.00702	.00600	.00543	.00507	.00480	.00445	.00402	.00366	.00342	.00320	.00304	.00290	.00282	.00276	.00270	.00264	.00256	.00250	.00246	.00242	.00236	.00234	.00230	.00228
		.316		66 370	.0165	.00933	.00668	.00577	.00523	.00490	.00465	.00431	.00394	.00354	.00338	.00312	.00296	.00286	.00276	.00270	.00264	.00260	.00252	.00246	.00242	.00236	.00232	.00230	.00226	.00224
		.281		52 630	.0143	.00872	.00638	.00555	.00505	.00474	.00451	.00420	.00382	.00350	.00330	.00306	.00290	.00280	.00272	.00264	.00260	.00254	.00248	.00240	.00236	.00232	.00230	.00226	.00224	.00222
		.250		41 740	.0129	.00822	.00612	.00533	.00488	.00460	.00437	.00407	.00368	.00338	.00322	.00300	.00284	.00274	.00266	.00260	.00254	.00250	.00244	.00238	.00232	.00228	.00226	.00222	.00220	.00218

x For three-phase regular flat spacing use $D = 1.26\ A$. For three-phase irregular flat or triangular spacing use $D = \sqrt[3]{ABC}$ For a two-phase line the spacing is the average distance between centers of conductors of the same phase.

TABLE IX—25 CYCLE CAPACITY SUSCEPTANCE TO NEUTRAL PER MILE OF SINGLE BARE CONDUCTOR

MICROMHOS PER MILE OF EACH CONDUCTOR OF A SINGLE-PHASE OR OF A SYMMETRICAL THREE-PHASE LINE—THE SUSCEPTANCE VALUES WERE DERIVED FROM THE EQUATION $b = 2\pi F C$ THE **CHARGING CURRENT** IN AMPERES **PER MILE** OF SINGLE CONDUCTOR TO NEUTRAL = THE (SUSCEPTANCE FROM TABLE) X (VOLTS TO NEUTRAL) X 10^{-6} THE SUSCEPTANCE BETWEEN CONDUCTORS EQUALS ONE HALF THE TABLE VALUES

CONDUCTORS					DISTANCE (D) BETWEEN CENTERS OF CONDUCTORS x																									
MATERIAL	TYPE	DIAMETER IN INCHES	B & S NO	AREA IN CIRCULAR MILS	½"	1"	2"	3"	4"	5"	6"	8"	12"	18"	2 FEET	3 FEET	4 FEET	5 FEET	6 FEET	7 FEET	8 FEET	9 FEET	11 FEET	13 FEET	15 FEET	17 FEET	19 FEET	21 FEET	23 FEET	26 FEET
COPPER	STRANDED	1631		2 000 000			213	115	920	790	710	618	523	453	415	370	346	328	313	303	294	286	275	267	260	254	249	244	241	237
		1548		1 800 000			189	110	878	763	692	603	5.13	446	408	356	341	325	308	300	292	283	274	265	257	252	247	244	239	236
		1504		1 700 000			177	107	862	750	681	595	508	443	406	364	338	322	306	298	288	282	272	264	257	250	246	242	239	236
		1459		1 600 000			168	105	845	738	671	585	502	4.40	404	360	336	320	306	296	286	280	271	262	255	249	246	241	237	236
		1412		1 500 000			159	102	825	723	660	580	498	435	398	3.56	335	318	304	293	285	278	269	260	254	249	244	239	236	232
		1369		1 400 000			151	986	805	710	648	573	489	429	394	353	332	315	300	291	282	276	267	259	252	245	241	237	234	230
		1263		1 200 000			136	928	772	683	626	554	478	420	385	347	326	310	295	287	280	273	262	256	249	244	249	236	232	227
		1209		1 100 000			129	903	750	670	613	545	474	415	382	344	323	305	293	285	278	270	261	254	247	241	247	232	230	227
		1152		1 000 000			122	870	732	655	601	535	462	408	377	339	317	303	290	282	275	268	259	250	245	239	234	232	227	225
		1123		950 000			119	862	723	645	594	529	457	405	373	337	316	300	288	280	273	266	257	250	244	239	234	231	227	224
		1093		900 000			116	845	712	638	588	524	454	400	371	334	315	298	286	278	272	265	255	247	242	237	232	229	226	222
		1062		850 000			113	828	700	630	580	517	452	397	368	333	313	296	285	276	270	263	254	246	241	236	232	229	224	222
		1031		800 000			110	810	690	622	575	513	444	395	364	331	310	293	283	275	268	262	254	246	241	236	231	227	224	221
		998		750 000			104	794	680	612	567	508	441	391	363	328	308	293	283	273	267	262	252	246	239	234	231	226	222	220
		.964		700 000		512	104	780	669	603	557	499	439	388	360	325	306	292	280	272	265	258	250	242	237	232	227	224	221	219
		929		650 000		358	995	763	657	593	550	494	433	383	356	322	303	288	278	270	263	258	249	242	236	231	227	224	221	218
		893		600 000		248	970	745	643	583	540	488	427	380	352	320	300	287	276	268	262	255	247	241	234	229	226	222	219	216
		855		550 000		244	935	727	630	572	533	479	420	376	348	316	297	283	273	267	258	253	246	237	232	227	224	221	217	216
		815		500 000		211	903	710	618	560	523	472	414	371	344	314	295	281	272	263	257	252	246	235	231	227	222	219	216	212
		772		450 000		186	870	690	603	548	513	464	409	365	340	309	292	278	268	260	253	248	241	234	229	224	221	216	214	211
		728		400 000		167	837	670	585	537	504	454	401	360	334	306	288	275	265	259	252	247	239	232	226	222	219	216	212	209
		681		350 000		150	807	648	570	523	490	445	394	353	330	3.02	284	272	262	255	250	243	236	229	225	219	216	214	209	207
		.630		300 000		136	770	625	550	507	477	434	385	347	324	296	280	267	258	252	245	240	232	227	221	217	212	211	207	204
		575		250 000		122	732	601	535	493	463	423	377	339	317	290	275	264	254	247	242	237	229	222	218	214	211	208	204	203
		528	0000	211 600		113	698	579	517	475	449	413	367	333	311	286	270	259	251	243	239	233	226	221	215	212	207	204	202	199
		.470	000	167 772	395	10.1	658	553	497	462	433	398	357	324	303	279	264	253	245	238	234	228	222	215	212	207	204	201	199	196
		418	00	133 079	228	928	625	528	477	440	418	386	347	316	297	273	259	248	240	234	229	225	217	212	207	204	201	197	196	193
		373	0	105 560	176	854	593	506	458	429	405	374	336	3.08	289	267	253	243	236	230	225	220	214	209	204	201	197	194	193	190
		332	1	83 694	145	794	565	485	440	412	391	363	328	300	283	261	248	239	231	225	222	215	211	204	201	197	194	192	189	187
		292	2	66 358	124	738	538	465	424	398	379	350	319	292	275	254	242	234	226	220	217	212	206	201	198	194	191	189	188	184
		260	3	52 624	111	710	516	447	410	385	366	340	312	285	270	250	237	229	222	217	212	209	203	197	194	191	187	186	184	181
		232	4	41 738	100	655	494	432	396	374	357	332	303	278	264	245	232	225	218	212	209	205	199	194	192	188	186	183	181	179
		.206	5	33 088	92	618	474	4.18	384	364	346	323	295	272	259	239	229	220	215	209	205	202	196	193	188	186	182	181	178	176
	SOLID	.460	0000	211 600	341	995	653	548	492	4.57	430	395	355	322	302	277	263	252	244	238	232	228	221	216	210	206	204	201	198	195
		410	000	167 772	206	9.11	619	524	4.73	442	415	383	345	313	294	271	257	247	239	233	228	224	217	212	207	203	201	197	194	192
		.365	00	133 079	168	845	588	502	456	423	402	372	335	305	287	265	252	242	235	228	224	220	214	207	203	199	196	194	191	189
		325	0	105 560	141	784	560	482	438	408	389	360	326	298	281	260	247	237	230	223	220	215	209	204	200	196	194	191	189	186
		.289	1	83 694	123	732	5.37	463	423	3.95	377	350	318	291	274	2.54	241	233	226	220	216	212	206	201	197	193	191	187	186	184
		.258	2	66 358	109	691	514	446	408	383	365	340	309	284	268	249	237	228	222	217	212	209	203	197	194	191	188	184	183	181
		.229	3	52 624	99	652	490	431	393	3.72	354	332	302	279	263	243	232	224	217	212	208	205	199	194	191	187	184	182	181	177
		.204	4	41 738	9.1	618	473	4.15	384	361	344	3.22	294	271	257	239	228	220	214	209	205	202	196	192	187	184	182	179	178	176
		.182	5	33 088	85	587	454	403	372	351	335	314	288	265	252	235	224	216	210	205	202	198	193	189	184	182	179	176	176	173
ALUMINUM	STEEL REINFORCED	953		605 000		445	103	7.72	750	600	560	498	434	386	359	324	305	290	278	270	265	258	251	244	237	232	227	224	22.	218
		904		500 000		30.7	9.78	755	647	584	544	488	430	381	354	320	302	287	276	268	262	256	248	241	234	231	226	222	219	216
		741		336 420		17.2	845	677	592	540	505	459	405	3.61	336	306	288	275	265	258	252	247	239	232	227	224	219	216	212	211
		635		266 800		13.7	775	628	554	510	480	435	385	348	324	297	278	267	259	252	245	240	232	227	221	217	214	211	208	206
		564		211 950		119	724	594	530	489	457	420	373	337	316	289	273	263	253	245	240	235	229	223	217	214	209	207	204	202
		501		167 800		10.7	681	565	508	468	442	405	362	327	308	282	267	257	248	242	235	232	224	219	214	209	206	204	201	197
		447		133 200	288	978	645	5.42	488	452	432	394	.352	319	300	277	262	250	243	237	232	227	221	216	209	206	204	201	198	196
		398		105 530	198	895	612	518	468	435	412	380	342	3.12	294	270	257	245	238	232	227	222	216	211	206	203	201	197	194	192
		355		83 640	160	8.25	582	4.98	450	420	398	369	333	303	283	265	252	240	233	228	224	218	213	208	204	201	196	194	191	189
		316		66 370	137	773	553	478	4.34	407	386	357	3.26	293	280	259	245	237	228	224	218	216	209	204	201	196	192	191	187	186
		281		52 630	11.8	722	5.28	460	4.18	393	373	348	317	290	2.74	254	240	232	225	218	215	210	206	199	196	192	191	188	186	184
		250		41 740	107	681	507	442	405	381	3.62	338	305	280	267	249	235	227	220	215	210	207	203	197	192	189	188	184	183	181

x For three phase regular flat spacing use $D = 1.26\ A$. For three-phase irregular flat or triangular spacing use $D = \sqrt[3]{ABC}$ For a two-phase line the spacing is the average distance between centers of conductors of the same phase.

TABLE X—60 CYCLE CAPACITY SUSCEPTANCE TO NEUTRAL PER MILE OF SINGLE BARE CONDUCTOR

M[illegible] PER MILE OF EACH CONDUCTOR OF A SINGLE-PHASE OR OF A SYMMETRICAL THREE-PHASE LINE—THE SUSCEPTANCE VALUES WERE DERIVED FROM THE EQUATION $b = 2\pi f C$. THE **CHARGING CURRENT** IN AMPERES **PER MILE** OF SINGLE CONDUCTOR TO NEUTRAL = THE (SUSCEPTANCE FROM TABLE) X (VOLTS TO NEUTRAL) X 10^{-6}. THE SUSCEPTANCE BETWEEN CONDUCTORS EQUALS ONE HALF THE TABLE VALUES.

MATERIAL	TYPE	DIAMETER IN INCHES	B. & S. NO.	AREA IN CIRCULAR MILS	½"	1"	2"	3"	4"	5"	6"	8"	12"	18"	2 FEET	3 FEET	4 FEET	5 FEET	6 FEET	7 FEET	8 FEET	9 FEET	11 FEET	13 FEET	15 FEET	17 FEET	19 FEET	21 FEET	23 FEET	25 FEET
					DISTANCE (D) BETWEEN CENTERS OF CONDUCTORS x																									
COPPER	STRANDED	1.631		2000000			[illegible]	277	221	190	171	148	125	109	995	8.90	833	788	753	[illegible]	708	689	660	640	27	608	598	585	577	569
		1.548		1800000			453	263	211	183	166	145	123	107	982	880	820	780	740	720	700	680	657	638	617	605	593	585	573	565
		1.504		1700000			427	257	207	180	164	143	122	106	975	872	812	773	737	[illegible]	693	677	653	633	617	600	588	581	573	565
		1.459		1600000			404	251	203	177	162	141	121	106	972	867	808	768	737	713	690	673	648	630	613	597	588	578	568	565
		1.412		1500000			383	245	198	174	158	139	119	105	955	856	805	765	733	705	685	669	645	625	608	597	585	573	565	557
		1.364		1400000			362	237	193	171	156	138	117	103	945	850	797	757	720	700	681	665	642	620	605	588	578	570	562	553
		1.263		1200000			327	223	186	164	151	133	115	101	927	833	784	745	710	690	673	651	628	613	597	585	573	565	557	546
		1.219		1100000			309	217	181	161	147	131	114	995	915	826	776	733	705	685	670	650	625	609	593	577	568	557	553	544
		1.152		1000000			293	209	176	158	144	129	111	980	905	814	762	728	697	678	660	645	622	601	588	573	562	557	545	539
		1.123		950000			285	207	174	155	143	127	110	972	896	810	760	720	693	613	657	642	617	601	585	573	562	553	545	537
		1.093		900000			278	203	171	153	141	126	109	962	892	805	757	717	689	669	653	638	613	593	581	569	558	549	542	533
		1.062		850000			211	199	168	151	139	124	108	955	885	800	752	713	685	665	650	633	609	593	577	565	558	549	538	533
		1.031		800000			263	195	166	149	138	123	107	950	875	794	745	705	680	662	645	629	609	589	577	565	553	545	538	529
		.998		750000			251	191	163	147	136	122	106	939	871	788	739	705	679	657	641	629	605	589	573	562	553	542	533	528
		.964		700000		230	249	88	161	145	134	120	105	933	865	783	736	700	673	653	638	622	600	581	568	557	545	538	530	525
		.929		650000		860	239	183	158	143	132	119	104	920	857	774	729	693	669	650	633	622	598	581	565	553	545	538	530	521
		.893		600000		598	233	179	155	140	130	117	103	912	845	768	720	688	665	645	629	613	594	577	561	549	542	533	525	517
		.855		550000		587	225	175	152	138	128	115	101	904	837	758	713	680	657	640	621	609	590	569	557	545	538	530	522	517
		.815		500000		507	217	170	148	134	126	114	995	890	826	754	709	675	652	633	618	605	592	565	554	545	533	526	518	509
		.772		450000		446	207	166	145	132	123	112	982	875	817	743	7.00	668	645	625	609	597	578	561	550	537	530	517	513	505
		.728		400000		402	201	161	141	129	121	109	962	865	803	735	693	660	637	622	605	593	573	557	542	533	525	517	508	502
		.681		350000		360	193	156	137	126	118	107	946	848	792	724	682	652	630	613	599	585	566	548	539	525	518	513	502	498
		.630		300000		326	185	150	132	122	115	104	925	835	779	710	673	642	621	605	590	578	558	542	528	522	510	505	497	490
		.575		250000		293	176	144	128	119	111	102	905	814	762	697	660	633	611	593	581	570	550	533	524	513	505	498	490	486
		.528	0000	211600		270	168	139	124	114	108	989	882	799	746	686	648	622	603	585	573	562	542	528	516	510	497	490	485	479
		.470	000	167772	950	243	158	133	119	111	104	955	856	777	728	671	633	607	588	573	562	550	534	518	509	497	490	482	478	471
		.418	00	133079	548	223	151	27	115	106	100	927	833	758	713	656	622	596	577	563	550	541	522	508	498	490	482	474	470	464
		.373	0	105560	424	205	143	12	110	103	973	897	807	739	694	640	607	584	566	553	539	530	514	502	490	482	473	466	462	456
		.332	1	83694	349	191	136	116	106	990	939	873	788	720	679	626	596	573	554	542	532	518	506	489	483	474	465	462	453	449
		.292	2	66358	299	177	129	112	102	955	909	840	765	701	660	611	581	562	543	530	520	510	494	482	475	465	457	454	450	441
		.260	3	52624	265	171	124	107	985	925	880	817	748	686	650	602	570	550	533	522	510	502	486	474	466	457	450	447	442	434
		.232	4	41738	241	157	119	104	950	897	856	796	728	667	633	588	558	539	524	510	501	494	478	466	460	450	445	438	434	430
		.206	5	33088	22	149	114	.00	922	873	830	777	710	653	622	573	550	530	518	502	494	486	470	462	450	446	438	434	426	422
	SOLID	.460	0000	211600	820	239	157	131	118	110	1033	950	852	773	725	667	631	606	587	573	559	550	530	518	506	494	490	482	474	470
		.410	000	167772	526	219	149	126	114	106	998	920	828	753	708	652	618	593	575	562	548	538	522	509	497	486	482	473	466	463
		.365	00	133079	404	203	142	120	109	102	965	892	805	734	691	638	605	582	564	550	538	530	513	498	489	478	470	466	458	455
		.325	0	105560	338	188	134	116	105	983	934	865	783	716	675	624	593	570	553	538	528	518	502	490	481	470	465	458	454	448
		.289	1	83694	295	176	129	111	102	950	905	840	763	699	659	611	581	559	543	530	519	510	493	482	473	462	457	450	446	442
		.258	2	66358	[illegible]	166	124	107	983	920	878	817	743	682	645	598	569	549	533	522	510	502	487	474	466	458	450	442	438	435
		.229	3	52624	239	157	118	104	950	892	850	797	725	670	633	585	557	538	522	510	502	493	478	466	458	450	442	438	434	426
		.204	4	41738	219	148	114	997	920	867	828	775	707	652	618	575	548	529	514	502	492	486	470	462	451	442	438	430	426	422
		.182	5	33088	204	41	109	965	892	843	803	755	693	638	606	565	538	518	506	493	486	478	462	454	442	438	430	422	422	414
ALUMINUM	STEEL REINFORCED	.953		605000		1070	247	186	179	144	135	120	104	928	862	778	733	697	669	650	637	622	601	585	568	558	545	537	530	521
		.904		500000		740	235	182	156	140	131	117	103	916	850	768	724	690	665	645	629	617	595	577	562	553	542	533	525	517
		.741		336420		412	203	163	142	130	122	110	972	865	808	737	693	661	638	622	605	593	513	557	545	537	525	517	508	505
		.635		266800		329	186	151	133	123	116	105	925	835	779	715	669	640	622	605	590	578	558	545	530	522	513	505	497	493
		.564		211950		287	174	143	128	118	110	101	896	810	758	695	658	633	608	590	578	565	550	534	521	513	502	497	490	486
		.501		167800		257	164	136	122	113	106	972	870	786	738	677	641	618	597	582	565	558	538	525	513	502	494	490	482	474
		.447		133200	693	235	155	130	117	109	104	945	845	766	720	665	629	602	585	570	557	545	530	517	502	494	489	482	474	470
		.398		105530	478	215	147	125	113	104	990	912	823	[illegible]	704	650	617	590	574	558	545	534	518	505	493	485	482	474	465	462
		.355		83640	384	198	140	119	108	101	957	885	800	729	682	638	605	577	562	550	538	525	510	497	490	482	470	466	458	453
		.316		66370	329	186	133	115	104	975	927	858	783	705	673	622	590	570	550	538	525	518	502	490	482	470	462	458	450	446
		.281		52630	295	174	127	11	101	945	898	837	760	697	657	610	577	557	542	525	518	506	494	478	470	462	458	450	446	442
		.250		41740	257	164	122	106	972	915	870	810	732	673	641	597	566	545	529	518	506	498	486	473	462	453	450	442	438	437

x For three phase regular flat spacing use $D = 1.26\,A$. For three-phase irregular flat or triangular spacing use $D = \sqrt[3]{ABC}$. For a two-phase line the spacing is the average distance between centers of conductors of the same phase.

TABLE XI—CHARGING K.V.A. IN THREE-PHASE CIRCUITS PER MILE OF THREE-BARE CONDUCTORS

CHARGING CURRENT **PER MILE** (EXPRESSED IN KVA 3 PHASE) FOR A SYMETRICAL 3 PHASE CIRCUIT AT THE AVERAGE VOLTAGES AND SPACINGS OF CONDUCTORS STATED. FOR OTHER ARRANGEMENTS OF CONDUCTORS SEE FOOT NOTES. x FOR OTHER SPACINGS THESE VALUES WILL VARY DIRECTLY AS THE SUSCEPTANCE VALUES OF THE SPACINGS COMPARED. THE CHARGING K.V.A. 3 PHASE = (CHARGING CURRENT IN AMPERES TO NEUTRAL) x (VOLTS TO NEUTRAL) x 3.

IN DETERMINING THE CHARGING K.V.A. FOR THE ENTIRE HIGH TENSION SYSTEM THE LENGTH OF ALL BRANCH CIRCUITS MUST BE INCLUDED AS WELL AS THAT OF THE MAIN CIRCUITS.

25 CYCLES

Material	Type	Diameter in Inches	B & S No.	Area in Circular Mils	20 KV 4 FT.	30 KV 4 FT.	40 KV 5 FT.	50 KV 6 FT.	60 KV 6 FT.	70 KV 7 FT.	80 KV 8 FT.	100 KV 9 FT.	110 KV 10 FT.	120 KV 11 FT.	140 KV 13 FT.	160 KV 17 FT.	200 KV 21 FT.
COPPER	STRANDED	1631		2 000 000	138	311	525	782	113	148	188	286	340	396	523	650	976
		1548		1 800 000	136	307	520	770	111	147	187	283	337	394	519	645	976
		1504		1 700 000	135	304	515	765	110	146	184	282	335	392	517	640	968
		1458		1 600 000	134	302	512	765	110	145	183	280	334	390	513	638	964
		1412		1 500 000	134	301	508	760	109	143	183	278	332	387	510	638	955
		1364		1 400 000	133	298	503	750	108	142	180	276	329	384	507	627	948
		1263		1 200 000	130	293	495	737	106	141	179	273	325	377	502	625	943
		1209		1 100 000	129	291	488	733	106	140	178	270	322	376	498	617	928
		1152		1 000 000	127	285	485	725	104	138	176	268	319	373	490	612	928
		1123		950 000	126	284	480	720	104	137	175	266	317	370	490	612	925
		1093		900 000	126	284	476	715	103	136	174	265	316	367	485	607	915
		1062		850 000	125	282	473	712	103	135	173	263	313	366	482	605	915
		1031		800 000	124	279	468	707	102	135	171	262	312	366	482	605	907
		998		750 000	123	277	468	707	102	134	171	262	312	363	482	598	903
		964		700 000	122	275	466	700	101	133	170	258	307	360	475	594	895
		929		650 000	121	273	460	695	100	132	168	258	302	358	475	591	895
		893		600 000	120	270	458	690	993	131	168	255	304	356	472	586	888
		855		550 000	119	267	452	682	982	131	165	253	301	354	465	581	884
		815		500 000	118	265	449	680	978	129	165	252	300	354	460	581	875
		772		450 000	117	263	445	670	965	127	162	248	295	347	458	573	863
		728		400 000	115	258	440	662	954	127	161	247	294	344	455	568	863
		681		350 000	114	255	435	655	943	125	160	243	290	340	448	560	855
		630		300 000	112	252	427	645	928	123	157	240	286	334	445	555	845
		575		250 000	110	247	422	635	915	121	155	237	282	330	435	547	832
		528	0000	211 600	108	243	413	627	903	119	153	233	277	325	433	543	815
		470	000	167 772	106	237	404	613	881	116	150	228	272	320	421	530	805
		418	00	133 079	104	233	396	600	864	115	147	225	268	312	415	522	788
		373	0	105 560	102	228	388	590	850	113	144	220	262	308	410	514	776
		332	1	83 694	99	223	382	578	832	110	142	215	256	304	400	504	768
		292	2	66 358	97	218	374	565	813	108	139	212	253	297	394	496	757
		260	3	52 624	95	213	366	555	800	106	136	209	249	292	386	489	745
		232	4	41 738	93	209	360	545	784	104	134	205	244	287	380	481	732
		206	5	33 088	92	206	352	537	774	102	131	202	241	282	378	476	723
	SOLID	460	0000	211 600'	105	237	403	610	878	116	148	228	271	319	423	527	803
		410	000	167 772	103	231	395	598	860	114	146	224	267	312	415	520	788
		365	00	133 079	101	227	386	587	845	112	143	220	262	308	405	510	776
		325	0	105 560	99	222	379	575	828	109	141	215	256	301	400	502	763
		289	1	83 694	96	217	372	565	813	108	138	212	253	297	394	493	748
		258	2	66 358	95	213	364	555	800	106	136	209	249	292	386	489	737
		229	3	52 624	93	209	358	542	780	104	133	205	244	286	380	478	728
		204	4	41 738	91	205	352	535	770	102	131	202	241	282	376	472	716
		182	5	33 088	90	202	346	525	755	100	129	198	236	278	370	465	704
ALUMINUM	STEEL REINFORCED	953		605 000	122	274	463	695	100	132	169	258	307	361	478	594	895
		904		500 000	121	272	458	690	993	131	168	256	305	357	472	590	888
		741		336 420	115	259	439	663	953	126	161	247	294	344	455	573	865
		635		266 800	111	250	427	648	932	123	157	240	286	334	445	555	845
		564		211 950	109	246	420	633	910	120	154	235	280	329	437	548	828
		501		167 800	107	240	410	620	893	118	150	232	276	322	429	535	816
		447		133 200	105	236	399	608	874	116	148	227	270	318	423	527	805
		398		105 530	103	231	392	595	857	114	145	222	265	311	413	520	788
		355		83 640	101	227	383	582	838	112	143	218	260	307	408	515	776
		316		66 370	98	220	378	570	820	110	140	216	257	301	400	502	765
		281		52 630	96	216	371	562	810	107	137	210	250	296	390	491	752
		250		41 740	94	212	363	550	792	105	134	207	246	292	386	484	737

60 CYCLES

Material	Type	Diameter in Inches	B & S No.	Area in Circular Mils	20 KV 4 FT.	30 KV 4 FT.	40 KV 5 FT.	50 KV 6 FT.	60 KV 6 FT.	70 KV 7 FT.	80 KV 8 FT.	100 KV 9 FT.	110 KV 10 FT.	120 KV 11 FT.	140 KV 13 FT.	160 KV 17 FT.	200 KV 21 FT.
COPPER	STRANDED	1631		2 000 000	333	750	126	188	271	356	453	689	813	950	125	156	234
		1548		1 800 000	328	739	125	185	266	352	447	680	803	945	125	155	234
		1504		1 700 000	325	730	124	184	265	351	443	677	802	940	124	154	232
		1458		1 600 000	323	728	123	184	265	349	441	673	[illegible]	933	123	153	231
		1412		1 500 000	322	725	122	183	264	345	437	669	[illegible]	928	122	153	229
		1364		1 400 000	318	715	121	180	259	343	435	665	[illegible]	925	121	151	228
		1263		1 200 000	314	707	119	178	255	338	431	651	770	905	120	150	226
		1209		1 100 000	310	697	117	176	254	335	428	650	770	900	119	148	223
		1152		1 000 000	305	685	116	174	251	332	422	645	765	895	118	147	223
		1123		950 000	304	683	115	173	249	329	420	642	760	888	118	147	221
		1093		900 000	302	680	115	172	247	328	418	638	757	883	116	146	220
		1062		850 000	301	677	114	171	246	326	415	633	750	876	116	145	220
		1031		800 000	298	670	113	170	244	324	413	629	745	876	115	145	218
		998		750 000	295	665	113	170	244	321	410	629	745	870	115	144	217
		964		700 000	294	662	112	168	242	320	408	622	737	864	114	143	215
		929		650 000	291	655	111	167	240	318	405	622	737	861	114	142	215
		893		600 000	288	648	110	166	239	316	402	613	728	855	113	141	213
		855		550 000	285	642	109	164	236	313	397	609	722	850	112	140	212
		815		500 000	284	638	108	163	234	310	396	605	[illegible]	850	111	140	210
		772		450 000	280	630	107	161	232	306	389	597	710	833	110	138	207
		728		400 000	277	623	106	159	229	305	387	593	704	825	109	137	207
		681		350 000	272	613	104	157	226	300	383	585	694	815	107	135	205
		630		300 000	269	605	103	155	223	296	377	578	685	803	106	134	202
		575		250 000	264	594	101	153	220	290	371	570	675	792	105	132	199
		528	0000	211 600	259	583	993	151	217	286	366	562	667	780	104	131	196
		470	000	167 772	253	570	970	147	212	281	359	550	652	770	102	127	193
		418	00	133 079	249	559	953	144	207	276	352	541	640	752	100	126	190
		373	0	105 560	243	545	935	141	204	271	345	530	627	740	983	123	186
		332	1	83 694	238	536	[illegible]	139	199	265	340	518	614	728	958	121	185
		292	2	66 358	232	522	898	136	195	260	333	510	[illegible]	712	944	119	182
		260	3	52 624	228	513	880	133	192	255	326	502	596	699	930	117	179
		232	4	41 738	224	502	863	[illegible]	188	250	320	494	587	688	912	115	175
		206	5	33 088	220	495	847	130	186	246	316	486	576	677	904	114	174
	SOLID	460	0000	211 600'	252	567	970	147	211	281	358	550	650	763	102	127	193
		410	000	167 772	247	556	948	144	207	275	351	538	638	751	995	124	189
		365	00	133 079	242	545	930	141	203	269	344	530	627	740	975	123	186
		325	0	105 560	237	533	912	138	198	263	338	518	615	723	959	120	183
		289	1	83 694	232	522	895	136	196	260	332	510	605	710	943	118	180
		258	2	66 358	227	512	878	133	192	256	326	502	595	700	929	117	177
		229	3	52 624	223	502	860	131	188	250	321	493	585	688	912	115	175
		204	4	41 738	219	492	846	129	185	246	314	486	577	677	905	113	172
		182	5	33 088	215	484	829	126	182	242	311	478	567	665	890	112	168
ALUMINUM	STEEL REINFORCED	953		605 000	293	659	112	167	241	318	407	622	737	865	115	143	215
		904		500 000	289	652	111	166	239	315	402	617	730	857	113	142	213
		741		336 420	277	623	106	159	229	304	387	593	703	825	109	138	207
		635		266 800	267	601	103	155	224	296	377	578	685	805	107	134	202
		564		211 950	263	591	102	152	218	289	370	565	670	792	105	132	198
		501		167 800	256	576	988	149	215	284	362	558	662	775	103	129	196
		447		133 200	251	565	[illegible]	146	210	279	356	545	645	763	101	127	193
		398		105 530	247	555	943	143	207	273	349	534	632	747	988	124	190
		355		83 640	242	544	922	141	202	269	344	525	622	735	973	123	186
		316		66 370	236	530	910	137	[illegible]	264	336	518	615	723	960	120	183
		281		52 630	231	518	893	[illegible]	[illegible]	257	331	506	603	712	935	118	180
		250		41 740	226	509	872	132	[illegible]	254	323	498	592	700	926	116	177

x For three-phase regular flat spacing use $D = 1.26\,A$. For three phase irregular flat or triangular spacing use $D = \sqrt[3]{ABC}$

Microfarads per 1000 feet of single conductor to neutral.

or

$$C = \frac{0.03883}{\log_{10} \frac{D}{R}} \qquad (16)$$

Microfarads per mile of single conductor to neutral.

The above formulas are only applicable to ordinary overhead circuits when the distance from the conductor to other conductors, particularly the earth, is large compared to their distance apart. However, since the effect of the earth is usually small in most practical cases, the formulas give a very close approximation to the actual capacitance of overhead circuits.

The values of capacitance in Table VIII were derived by using formula (13). For calculating the capacitance for the stranded conductors, the actual overall diameter of the cable was taken. This introduces a small error which is negligible except for very close spacings not used in high tension transmission lines employing bare conductors.

CHARGING CURRENT

RELATION OF CHARGING CURRENTS OF SINGLE AND THREE-PHASE SYSTEMS

The diagrams (Fig. 11) may assist in forming a clear understanding of the relation of charging current

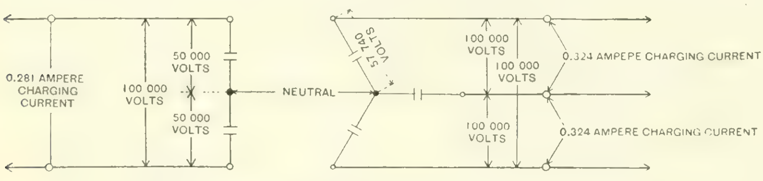


FIG. 11—CHARGING CURRENT IN SINGLE AND THREE-PHASE CIRCUITS

to susceptance for single and three-phase circuits. In the following consideration No. 0000 stranded copper conductors will be assumed as spaced nine feet between any two conductors, frequency 60 cycles, voltage 100 000 volts between conductors. Voltage to neutral will therefore be, for single phase circuit, 50 000 volts and for three-phase circuit 57 740 volts. Distance of transmission one mile. From Table VIII, a capacitance to neutral of 0.00282 microfarads per 1000 feet is obtained which is equivalent to 0.0149 microfarads per conductor to neutral for this one mile of circuit. The susceptance will therefore be as follows:—

Per conductor to neutral $2 \pi f C_n = 5.62$ microhms
Between conductors $2 \pi f C_{12} = 2.81$ microhms

For Single-Phase Circuit—To neutral $5.62 \times 50\,000 \times 10^6 = 0.281$ amperes or between conductors $2.81 \times 100\,000 \times 10^6 = 0.281$ amperes therefore charging k.v.a. is $0.281 \times 50\,000 \times 2 = 28.1$ k.v.a. single phase or $0.281 \times 100\,000 = 28.1$ k.v.a. single phase.

For a Three-Phase Circuit—To neutral $5.62 \times 57\,740 \times 10^6 = 0.324$ amperes. Therefore charging k.v.a. is $0.324 \times 57\,740 \times 3 = 56.2$ k.v.a. three-phase.

It will be seen from the above that the charging current per conductor in the three-phase symmetrical system is 15.5 percent greater than in the single-phase system, and the resulting charging k.v.a. is just double that of the single-phase system. The charge on any particular conductor is in phase with the voltage between that conductor and the neutral and the charging current for that conductor is 90 degrees ahead of the voltage drop from that conductor to neutral.

Grounding of the neutral point of a system has no effect upon the charging current when the system is in static balance. In determining the total charging current to be supplied by a given generating station, it should be remembered that in cases of duplicate transmission circuits, when both circuits are excited, the charging current will be approximately double what it would be if only one of the circuits were in use.

Tables IX and X contain values for capacitance susceptance to neutral in microhms per mile of conductor. As indicated, the charging current in amperes per mile of single conductor to neutral = the (susceptance from table) $\times$ (volts to neutral) $\times$ 10^{-6}. Thus in a three-phase, 60 cycle, 100 000 volt, (57 740 volts to neutral), symmetrical circuit, the No. 0000 stranded conductors being arranged at the corners of an equilateral triangle spaced nine feet apart, the charging current per mile would be determined as follows:—

$5.62 \times 57\,740 \times 10^{-6} = 0.3245$ amperes to neutral

or $0.3245 \times 57\,740 = 18.737$ k.v.a. to neutral

$18.737 \times 3 = 56.2$ K.v.a. total three phase

Table XI is an extension of Tables IX and X from which values in k.v.a., three-phase for charging current have been calculated for certain assumed spacings and average voltages. In the case cited above it was found that the charging current would be 56.2 k.v.a., three-phase per mile. Table XI gives this value directly for the conditions specified.

CHARGING CURRENT AT ZERO LOAD

The term charging current of a transmission circuit refers to the amount of current which flows into the circuit at the supply end with normal voltage held at the receiver end at *zero load*. If the circuit is long, its capacitance will be high and therefore the voltage at the supply end may be considerably less than at the receiver end. For instance a 60 cycle circuit 300 miles long, having certain constants will, with 100 000 volts maintained at the receiver end, have a voltage of only 80 000 volts at the supply end at zero load. This same circuit will at full load and 100 000 volts maintained at the receiver end, require 120 000 volts at the supply end. It is evident therefore that, since the charging current varies with the voltage, if the circuit has much capacitance the voltage along the circuit, and particularly near the supply end, will vary to a large extent

and consequently the charging current of the circuit will be different for different loads.

In case of the 300 mile circuit referred to above, the charging current at zero load will be very much less than it is at full load, because the average voltage at zero load is less than the average voltage at full load. At zero load the average voltage is less and at full load it is greater than the receiver end voltage.

It is customary to calculate the total charging current for the circuit by multiplying the total susceptance by the receiver end voltage. This would be correct if the voltage throughout the length of the circuit were held constant and of the same value as at the receiver end. This condition is approximately met within commercial lines and this method of determining the total charging current is therefore sufficiently accurate for most practical purposes.

For the purpose of making exact calculation of the total current at the supply end of long circuits, the charging current must be calculated by mathematical formulas which accurately take into account the change in voltage along the circuit at zero load. This will be taken up in a later article. It may be interesting to note approximately, however, how the charging current and charging k.v.a., as determined by the above method, varies from what it would be if calculated by the rigorous formula. The curves in Fig. 12 represent an approximation to the error when calculating the charging current at zero load by multiplying the total susceptance by the receiver voltage. For a circuit 300 miles long the error in charging current is only two percent for 25 cycles and seven percent for 60 cycle circuits. The error in charging k.v.a. is four percent for 25 cycle and 32 percent for 60 cycle circuits.

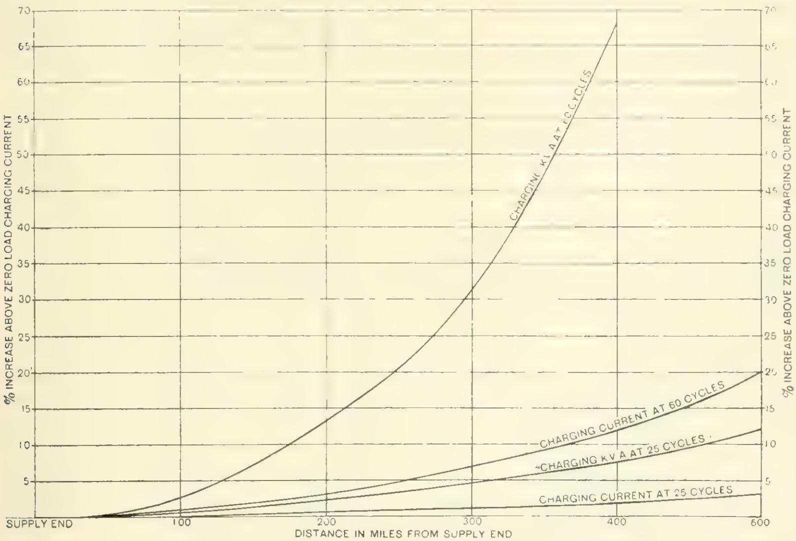


FIG. 12—CHARGING CURRENT AT ZERO LOAD FOR VARIOUS LENGTHS

At zero load the voltage (on account of the effect of capacitance) decreases as the supply end of the circuit is approached. The charging current at points along the circuit decreases directly as the voltage. If the charging current for zero load is estimated by the approximate method based upon the receiver voltage being maintained throughout the length of the circuit the result will be too high. The error will increase as the length of the circuit is increased; it will also increase rapidly as the frequency is raised. The error in the resulting K.V.A. required to charge the circuit will therefore increase very rapidly with an increase in distance or frequency. The curves below represent an approximation of this error.

RELATION OF INDUCTANCE TO CAPACITANCE

As conductors are brought closer together, the inductance decreases and the capacitance increases. These values change with changes in spacings between conductors in such a manner that their product $L \times C$ is practically a constant for all spacings (except very close spacings such as used in low-voltage service and lead-covered cables) and for all sizes of conductors. If there were no losses encountered by the electric propagation in the conductors themselves the product of L and C would be a constant for all spacings and sizes of conductors.

In Table C is indicated the relation of the total inductance and capacitance, and their product, in two bare parallel conductors in air for a circuit one mile long. The values for L are in millihenries and for C in microfarads. Since the formulas by which L and C were calculated account for the flux within the conductors themselves, the product LC is not a constant, as will be seen by the tabulated values, although for the larger spacings such as used in high-tension transmission the product is nearly a constant.

TABLE C—PRODUCT OF (TOTAL) L AND (TOTAL) C

Solid Conductors: Size	Solid Conductors: Diam. Inches	Spacing Inches	Inductance L Formula (4)	Capacitance C Formula (14)	Product L C
1 000 000	1.00	2	1.053	0.03395	0.03575
1 000 000	1.00	24	2.653	0.01155	0.03064
1 000 000	1.00	300	4.279	0.00695	0.02974
0000	0.46	2	1.553	0.02079	0.03228
0000	0.46	24	3.153	0.00961	0.03030
0000	0.46	300	4.779	0.00623	0.02977

RELATION OF INDUCTANCE AND CAPACITANCE TO LIGHT VELOCITY

The propagation of the electric and the magnetic

fields in a dielectric, such as air, is the same as that of light. Along a transmission line it is retarded only slightly due to losses or the fact that the current is not confined to the surface of the conductors. If the inductance inside the conductors is negligible, then the velocity of the electric and the magnetic fields is the same as light, that is approximately 186 000 miles per second or approximately 3×10^{10} cm. per second. For high-tension transmission lines of large spacings, the inductance inside the conductor is relatively small, so that the speed of the electric field is practically that of light.

The following relation exists between inductance L in henries, capacity C in farads and velocity of light V per second:—

$$LC \text{ (in air)} = \frac{1}{V^2} \text{ or, } V = \frac{1}{\sqrt{LC}} \quad \ldots\ldots\ldots \quad (17)$$

Thus it will be seen that if either L or C is known, the other may be determined since the velocity of light V is known. If values for L and C are taken which include the inductance inside the conductors, particularly if the conductors are very close together, it would be necessary to assume a velocity of electric propagation somewhat less than that of light. If, on the other hand, the values for L and C external to the conductors are taken, then the above equation is rigidly correct.

In Table C, it was shown that for No. 0000 conductors, 300 inch spacing, the total values of L and C were for a single-phase line,—

$L = 0.004\,779$ henries per mile of circuit.
$C = 0.000\,000\,006\,23$ farads per mile of circuit.

therefore, $V = \dfrac{1}{\sqrt{0.004\,779 \times 0.000\,000\,006\,23}} =$
183 000 miles per second .... (18)
which is less than the speed of light.

If we take the inductance in the air space between the conductors, Formula (2); we arrive at the values,—

$L = 0.004\,617\,9$ henries per mile of circuit.
$C = 0.000\,000\,006\,23$ farads per mile of circuit.

therefore $V = \dfrac{1}{\sqrt{0.004\,617\,9 \times 0.000\,000\,006\,23}} =$
186 000 miles per second .... (19)
which is approximately the speed of light.

Electrical Insulating Materials

R. P. Jackson

When the first facts of electrical science were learned by the early investigators, among the most important ones was that some materials were conductors while others did not seem to conduct electricity and so were classed as "dielectrics" or "insulators". In the development of electrical apparatus it soon appeared that this quality of insulation was just as important as that of conduction in the other class of materials. The one class provided a path for the electric current while the other kept the current from straying from this path.

Why some materials were conductors and others not, was not understood and is only now in a measure explained by the statement that all matter contains minute particles called electrons and that these electrons have various degrees of mobility in various materials. In those materials in which free electrons are plentiful and mobile, a current of electricity is nothing more than the emigration of these electrons under the impulse of an electromotive force. In those materials in which the free electrons are few and comparatively immobile, but very feeble currents can be set up by an electromotive force. Such materials are termed "insulators", but in reality they are only comparatively poor conductors.

It was early determined sufficiently for generalization that metals were conductors. Few general rules, however, have been worked out as to what materials were necessarily non-conductors. One such generalization made by Maxwell is that solid transparent materials must be insulators. This conclusion is based on the fact that light is an electromagnetic radiation and such radiation penetrating a conductor at once produces local electron movement with absorption of energy and therefore of the radiation. The very fact of transparency in the case of material not an electrolyte is proof of its non-conducting quality. The converse, however, is not true as insulators are frequently opaque. They are usually of complicated structure and probably possess some radiation absorbing element independent of the insulating constituent. Electrolytes, while often transparent, are apparently conducting in a much different manner from metals and presumably would be non-conducting at frequencies approaching that of light.

For practical purposes all insulating materials may be divided into the two classes of organic and inorganic.

The inorganic materials are chiefly of value due to their ability to withstand weather or high temperature, or both. The following are fairly well known inorganic insulators:—porcelain, glass, marble, lava, soapstone, mica, asbestos, etc. The characteristics of each will be discussed later.

The organic materials cover a wide field and, in general, involve compositions, some parts of which are the products of plant growth or hydrocarbons of perhaps unknown origin such as the so-called mineral oils. They are all subject to carbonization, i.e., burning at temperatures that would not affect the inorganic materials. The following are some of the commoner

types of organic insulations; there is such a variety of them with various trade names that it is practically impossible to make a complete list:—

Paper, in all its forms and treatments
Cloth, in all its forms and treatments
Wood
Varnishes
Gums, asphalts, pitches, waxes, etc., commonly used either for varnish making or for filling or impregnating purposes
Synthetic resins, such as bakelite, condensite, redmanol, etc.
Rubber and similar materials
Oils—vegetable and animal
Oils—mineral or petrolic in origin.

A great variety of special adaptations of the various materials and combinations of them are in common use.

INORGANIC OR MINERAL MATERIALS

Porcelain as used for electrical insulation is essentially a fused mixture of clay, flint, and feldspar. To make a serviceable insulator there must be a balance between these three materials. The mechanical strength varies directly with the flint content, the resistance to local heating varies with the clay while the feldspar furnishing the alkali element tends to give a translucent, glossy texture and increases the dielectric strength, but also the brittleness. After a satisfactory balance has been obtained between mechanical strength, dielectric strength and resistance to temperature changes, there is nothing to gain by varying the proportions so long as the same materials are used. It has been found that if a soda instead of a potash feldspar is used there is an absence of ring and the resilient texture of the porcelain is replaced by a certain deadness. There has been produced a special type of porcelain for spark plugs in airplane and automobile engines with magnesia as one of the constituents, that gives good mechanical strength and special virtues in resistance to heat. It also retains its dielectric strength up to surprisingly high temperatures. Ordinary porcelain begins to lose its electrical strength at about 300 degrees C.

Ordinary electrical porcelain has a tensile strength of approximately 3000 pounds per square inch under fair conditions. In general, however, it is undesirable to use it in tension where the service is important unless the stress is low and free from shocks. Under compression, porcelain is reliable and has a crushing strength of about 20 000 pounds per square inch. Efforts to use porcelain in suspension for line insulation are looked on with suspicion, but if the mass of the piece is great enough and the mix rather high in flint, there is no reason why such use should not be successful for moderate loads.

The glaze on porcelain is essentially a glass coating sufficiently fusible to melt and assume a brilliant surface at the firing temperature of the porcelain. It must have the same temperature expansion coefficient as the porcelain. If greater, the glaze will craze on cooling and show fine hair cracks. If less, the result will be shivering or fine chipping off of the glaze. The glaze contributes practically nothing to the dielectric strength of properly fired porcelain but is of value to give a definite color and a brilliant cleanable surface to the ware.

In general, at the present time, the quality of electrical porcelain is dependent not so much on the knowledge as to what is the proper mix of materials as upon the care and integrity manifested in the preparation of the materials, the fabrication and testing of the product.

Glass as an electrical insulator was used very early in the art because of its obviously good insulating quality. It was early discovered, however, that it had the faults as well as the virtues of a porcelain very high in feldspar, that is, while its insulating strength is high and its fracture clean and bright, it was found to be brittle and very subject to fracture from very moderate temperature variations.

The expansion temperature coefficient of the ordinary glass such as used in insulators is 7 to 8, as compared to 5 to 6 for porcelain. Another difficulty that developed with the glass used in insulators is the weathering and disintegration of the surface in contact with moisture. This is not true of all glass by any means but is likely to be a troublesome factor with the ordinary cheap glass which it has been considered necessary to use for the manufacture of insulators. If a glass of low temperature coefficient of expansion and good weathering qualities should be put on the market at a price at all comparing with porcelain, there would be a fair chance of its coming into use for high voltage insulation. It would have the obvious advantage of uniformity of dimensions and ease of inspection due to transparency.

Glass has been used at times as the dielectric of static condensers. Unless special provision can be made for cooling, however, it is not very satisfactory. Used at a high electric stress, as it must be to be efficient as a condenser, glass has internal dielectric losses which cause local heating and cracking. The so-called "Moscicki" condensers, made of a special imported glass in the form of a long bottle with a thick neck have been used for some time in wireless work. The special features that made them successful were a quality of glass that had very low dielectric losses and a shape of bottle with a thick narrow neck at the point where the plating ended. This reduced the stress and corona at this critical location.

Glass in general is not a crystal but a solid colloid. It has more the nature of a mineral gum in a very hard state. Glass again is only a generic name for a very wide variety of compositions usually having silica as a constituent. The qualities of different glasses vary greatly and, while the use of glass for insulation purposes has not been increasing of late years, its use or rejection should be based only on the adaptability of the glass available to the use contemplated.

Marble is a pure rock of calcium carbonate which has undergone sufficient heat to cause recrystallization. It does not compare with porcelain or glass as an in-

sulator. Marble is well suited to such low voltages as 2500 but for higher potentials should not be used for switchboard work or otherwise except under very special precautions. When direct-current of 1000 volts or over is used on marble in air, the marble should be soaked in insulating varnish and then baked or some similar treatment should be applied.

Marble takes a good polish but shows oil spots and, for that reason, is now stained black and given a so-called marine finish to avoid the difficulty of oil stains and matching up of color. Being a limestone, marble should not be subjected to temperatures sufficient to drive off its CO_2 as it would then slake and disintegrate. Good marble has a transverse bend strength of about 1500 pounds per square inch and a compression strength of about 10 000 pounds per square inch.

Slate is a material which can be cut into plates or slabs and used in a way similar to marble. It has certain advantages over marble, particularly in regard to strength and cheapness. For example, its transverse bending strength is about 7500 pounds and it has a compressive strength of 20 000 pounds. Like marble it is mostly used for switchboards with a black finish. It is not considered quite equal to marble electrically, but is suitable for general low voltage work. Both slate and marble are chiefly of value for plates for switch mounting and are not suitable for bushings nor are they in any way competitive with glass or porcelain. Slate itself does not take a polish unless varnished. It can be drilled with comparative ease.

Soapstone in the raw state is often used where cheap bulky slabs are required for barriers, bushing supports, etc. Its use is now limited to barrier applications where it is set in cement and serves to isolate possible arcs. It stands heat better than the other plate materials but does not take a polish and is not particularly reliable as an insulator for any but moderate voltages.

Lava—A material sold under the trade names of "Lava" or "Lavite" is essentially a natural rock called steatite similar to soapstone that, after machining to shape, is baked or fired at a high temperature i. e. 1100 degrees C. Lava, being a machine-cut product, can be obtained in very accurate shapes. The pieces are limited in size to six to eight inches for any dimension. The insulating quality is high, comparing favorably to porcelain, and its resistance to heat is great. For that reason it is particularly suited for insulating spools on which heating elements are to be wound. As it can be cut in the soft condition and is very hard and strong after firing, it can be made up threaded or with grooves or small deep holes for wires. Being, in general, made from a natural rock, it is necessary in manufacture to select carefully the material to avoid laminations. It is two to three times as strong as marble and stands heat very much better. It absorbs moisture, however, and therefore is not in general a substitute for porcelain.

Mica is a crystal of the monoclinic system provided with a multitude of cleavage planes. Its composition may vary largely as to basic elements but in general is a compound of silicates of alumina and an alkaline metal. "Muscovite" or potash mica has a composition of $H_2K\ Al_3\ (SiO_4)_3$, while "Phlogopite" or magnesia mica has a magnesia content which may be considered as a partial substitute for the potash. This is the variety commonly known as "Amber" mica. While mica is ordinarily split to flakes about 0.001 inch in thickness, there seems to be no particular limit to the thinness of cleavage. Small flakes 1-300 000 inch thick have been found. In fact, the ultimate thickness of cleavage layers is unknown and may be finally but one layer of the molecular structure.

Artificial mica is sometimes found in slags and has been produced by Von Chrustachoff by fusing alumina, potash and silica in a platinum crucible and allowing to cool very slowly, when small mica crystals 2 to 3 mm. square were found in the cooled mass. The size of crystals is dependent on the slowness of undisturbed cooling. An idea of geologic time may be obtained from the fact that mica crystals have been found weighing 20 tons. A crystal was found in the Inikurti mine in India 10 feet deep by 15 feet across.

Mica is found in many parts of the world in rocks of coarse granitic structure. It appears irregularly in the form of "books" or packages of flake crystals which when separated from the rock and trimmed can be split into sheets of thickness down to about 0.001 inch. Flakes thinner than this are rather too fragile to handle. If the splitting produces thicker flakes or "heels", i. e. thick edges or corners, the product is unsatisfactory for some electrical uses. Some mica crystals have been subject to uneven rock pressure so that wrinkles have been formed. Such wrinkles usually have to be eliminated before splitting.

While for electrical purposes mica is commonly graded as "amber" or magnesia mica and as "white" or potash mica, yet there are a variety of others not common on the American market. They may be graded as to softness as follows:—

1—Amber mica.
2—White India Mica
3—Soft green Madras and Calcutta mica.
4—Ruby Indian mica.
5—Hard green and brown Madras.
6—Green, brown and yellow East African
7—Green U. S. Mica.

The amber while classed as soft may be graded as follows:—

1—Clear transparent soft amber.
2—Streaked amber of medium hardness.
3—Opaque hard amber.

Amber mica on account of its softness is preferred for commutator segments because its softness permits it to wear down flush with the copper segments more readily than the harder white mica. More recent practice, however, is to undercut the mica 1/16 inch below the level of the copper and use either white or amber.

To be made use of industrially mica has to be built up into sheet or wrapper or plate by means of a binder. For some work flakes of mica are built up by hand with

a shellac binder until a thickness is obtained suitable for separators for commutator segments. It is then pressed under heat to drive out the solvent in the shellac and after sanding off to a definite thickness is ready for punching to shape. A similar product can be made with very little handwork by dropping the mica flakes in a tower with a dry powdered bond which is afterwards melted in the hot press, thereby sealing all the flakes together.

For coil wrappers the mica flakes, which must be of good quality, are built onto a thin sheet of tough paper. The bonding varnish should be of a character to remain soft for some time and permit the wrapper to be applied and rolled tightly to the coil and bend around the corners without breaking. For parts of coils where a long wrapper is unsuited a mica tape consisting of flakes built upon a very thin paper is used. After cutting into strips such tape can be wound spirally with overlap in the same way as ordinary tape except that care must be used, as the strength is not great. Such taping must be protected by a cloth tape where it is not covered by a final wrapper.

A special and very satisfactory application is obtained by building large high grade mica on a tough thin paper with shellac. This wrapper is then wound loosely on the straight part of the coil by hand after which it is ironed down by rotating hot iron bars that are arranged to float around the coil in contact with the wrapper in such a way as to melt the shellac and draw the wrapper up tight. The coil is then clamped in an accurate form and allowed to cool. The result is a coil the straight portion of which is encased in a hard mass of which 75 percent is mica sealed together with shellac. This process of applying "micarta folium" gives a particularly firm durable heat-resisting insulation of high dielectric strength for the straight portions of large generator coils.

Certain qualities of mica give it an outstanding virtue for insulating purposes. It is not hygroscopic, that is, it has no natural tendency to absorb moisture. It is not readily affected by corona or electric discharge over its surface. This particularly adapts it to use on high voltage generators where corona is liable to be present at the end of the slots. Organic insulation will be eaten through and fail in time under the action of corona.

Another valuable feature of mica is that through the range of generator temperatures it retains its dielectric qualities with but very moderate change. Its insulation resistance, of course, drops a trifle with rising temperature but practically the result with rising temperature is generally an increase of insulation watt-loss for a time until all free moisture is eliminated, after which the losses fall off and drop to a figure but little above those for room temperatures. Thus coil wrappers possessing a large amount of mica have a distinct advantage over organic wrappers the losses in which at higher temperatures frequently rise to a dangerous point. In fact, it is possible for the losses in a high voltage generator to reach a value commensurate with the full-load copper losses in the windings. When such a condition is reached the situation is unstable and the machine may burn out even though the load be reduced. The insulation losses cause the temperature to continue to rise and the elevated temperature causes increased insulation losses. Large generator windings that may be subject to severe heating are, therefore, much more stable and reliable if mica is insulated than if reliance is placed on a wholly organic insulation.

For heating apparatus such as smoothing irons, where the mica is in contact with red-hot conductors, only special grades of mica are suitable. While theoretically mica does not contain water of crystallization yet most mica actually does contain some water and when heated to 400 to 600 degrees C. turns to a silvery opaque condition and becomes very soft. Some grades, however, will retain their structure up to 800 degrees and above. While necessity may be the mother of invention, it is hard to see how the present development of electrical apparatus would have been possible without mica.

Asbestos—Like mica, asbestos is a peculiar crystal of silica, magnesia, alumina and water. Instead of having cleavage planes it cleaves into innumerable fibers. As mica cleaves into exceedingly thin flakes or sheets, so asbestos even under a magnification of 900 diameters still shows fibers so small as to be hardly discernible. It has been suggested that the ultimate undividable fiber will be a single row of the molecular structure of the crystal.

Asbestos apparently has crystallized out of the surrounding serpentine rock, the chemical nature of which is the same, into crevices and cracks which have been formed by earth movement. These crystals appear to grow out from each face of the rock much like frost crystals push up from decaying peat or sawdust. Frequently the crystals growing out from the opposite faces appear to have met in the center of the fissure where a layer of grit and rock particles form which have been carried on the head of the advancing crystals.

Two kinds of white asbestos are found "Chrysotile" and "Amphibole". The latter is higher in silica, lime and iron, lower in magnesia and water than the former. While somewhat more resistant to heat and acid it is rather brittle. It is not much used for that reason. It is the Chrysotile that is commonly used for insulation work and our supply comes largely from the province of Quebec.

At first there was great difficulty in spinning asbestos fiber after it has been crushed and beaten into the fine fluffy mass resembling cotton. While wool, cotton and silk have more or less roughness on the surface of the filament, asbestos is absolutely smooth and glossy. This condition failed to provide the friction necessary to give strength to the spun thread. This difficulty has been partly overcome, however, and fairly strong fine thread can be made of long fiber as-

bestos though not equal to good cotton or linen.

For electrical insulation asbestos is used in the form of paper or as a cloth, as tape, as a wrapper on wire, as a board when cemented together by a suitable binder and as a filler and strength element in molding mixtures. Its chief advantage is that it is non-combustible and does not fuse at any temperature encountered in electrical apparatus, except adjacent to an arc. Its main disadvantage is that it is somewhat hygroscopic and therefore does not have insulating values suitable for high voltage use. Asbestos insulation should in general never be used in connection with voltages of 3300 and above.

Another limitation is the presence in the fiber of small particles of iron oxide or magnetite like scale or grit. These particles are very small but several may sometimes be found with a microscope in a square inch of paper. While the resistance of each such particle is usually fairly high yet, in the aggregate, they may at times cause appreciable leakage current. There is no known way of entirely eliminating these iron oxide particles without seriously damaging the asbestos fiber.

Wherever the insulation strength required is moderate and a heat-resisting or non-combustible material is needed, asbestos serves a very useful purpose. It is nowhere near as essential as mica but the electrical industry would be distinctly embarrassed by its absence.*

ORGANIC MATERIALS

When organic insulating materials are considered, it is impossible to give their characteristics in such detail as in the case of the mineral materials because there are so many varieties and adaptations of each one. The general nature of such characteristics, however, and certain limitations can be indicated.

Paper or similar felted fiber materials have been used since the very beginning of the electrical industry. This type of material ranges from the thinnest rice tissue paper used in condensers to heavy fullerboards and massive sheets of fiber as much as one inch in thickness. In general, while all varieties are made from some vegetable fiber, the product is of two general types, i.e., that in which the fiber or pulp is simply compressed into a paper and that in which the fiber has been specially digested or parchmentized to give a close grained colloidal or cellulose texture. Kraft paper and fullerboard are samples of the former, while fish paper and hard fiber are of the second. The former may receive a sizing treatment of glue solution to harden the surface.

The thinner grades of paper are used chiefly either as a foundation on which to build mica for coil wrapper purposes or with a varnish treatment to close the pores and give it a more definite dielectric value and somewhat increase its resistance to heat or moisture. A special use is that now extensively made of the kraft or wood pulp paper in the manufacture of micarta, described later. Plain untreated paper has no great dielectric strength since its pores are not closed but filled with air and may easily become filled with moisture. It is chiefly of value as a vehicle or framework to hold other materials of higher dielectric value such as oil, varnish or impregnating gums.

Material that has been through a special digesting or parchmentizing process is used principally on account of its hardness and strength and resistance to abrasion. For example, fish paper and thin fiber is used for slot cells to protect the coil insulation from cutting by the edges of the iron laminations and for wedges to hold the coils in place. Fish paper is also used to some extent as a separation between coils of small service transformers. One feature of this type of paper is that the digesting or parchmentizing process has involved some active chemical, like sulphuric acid or zinc chloride which afterwards, in the process of manufacture, has to be carefully washed out. If this is not done the action of such treating chemical continues, especially when subjected to heat, and the product is liable to become very brittle and even disintegrate.

There are, also, papers and boards having asbestos as a body, their heat resisting qualities are, of course, beyond the range of that of organic materials but they are inferior as to insulating quality, unless reinforced by some organic binder which, in a measure, sacrifices the heat-resisting character.

The following is a list of the principal materials of the paper type in use for insulating work:—

NAME	ORIGIN	METOD OF MANUFACTURE
Linen paper	Linen Scrap......	Compressed and sized
Kraft	Wood pulp	Sulphate treatment unsized
[illegible]	Old rope	Compressed and unsized
[illegible] board	Cotton rags	Compressed and sized
Fullerboard	Cotton rags	Compressed and unsized
Fish paper	Cotton rags	Digested H_2SO_4
Hard fiber	Cotton rags	Digested $ZnCl$
Asbestos paper .	Asbestos and cotton fiber	Compressed, unsized
Asbestos lumber	Asbestos & hydraulic cement	Compressed, unsized
Asbestos board .	Asbestos and water glass	Compressed and heated
Paper micarta	Kraft paper & shellac or bakelite	Compressed and heated
Duck micarta ..	Cotton duck & bakelite.	Compressed and heated.

Cloth—There came into use some twenty years ago a material known at the time as "empire cloth", which consisted of a white cotton cloth (cambric) treated with a linseed oil varnish that left it in a soft flexible condition but having a high insulating quality. In one form or another this type of material continues in use extensively today.

For the very finest work on ignition magnetos and similar work varnished silk is preferable on account of its extreme flexibility and high dielectric strength per mil of thickness. Varnished silk can be obtained in thickness down to 0.003 to 0.004 inch.

*See article on "Asbestos" by H. R. Edgecomb, in the JOURNAL for January 1911, p. 82

Treated cambric is made with either clear or black varnishes and in either smooth or tacky surface. By "tacky" is meant a surface somewhat sticky so that layers adhere together when put on as a tape. Treated cambric can be obtained in thicknesses of from 0.007 to 0.012 inch, depending on the number of dips of varnish applied. Ordinarily the varnishes are composed of linseed or similar oils with copal gum, etc. or in case of the black varnish some variety of asphalt may be included. Special applications of treated cloth are friction tape in which the treatment is usually a rubber composition. Similar tapes are made with pitch or asphalt treatment. The idea is to provide an adhesive "dope" that will seal the layers together and finally harden with age into a compact insulating mass. Tapes may be woven to width or cut straight from wider stock or cut from stock that has been spliced on the bias and resewed. This latter method gives a tape with all threads running diagonally across it, thus permitting it to stretch and pull down on curved surfaces smoother than straight cut tape.

For severe conditions of mechanical stress, heavy drilling or even cotton duck is treated with oil or pitch varnishes.

It sometimes appears in examining samples of treated cambric that some have a beautifully glossy smooth surface while others have rough or pimply surfaces. A clean firm cambric that has been singed to eliminate the stray nap of cotton fibers and then partially filled will give a reasonably smooth surface after treatment and at the same time retain a high dielectric strength. Extreme filling and sizing of the cloth before calendering and varnishing will give a finer finish and nicer appearance but the excessive starch prevents the varnish from filling the cloth. The result is two films of varnish, one on each side of the cloth with a starch and cotton layer between with impaired insulating and mechanical qualities. In addition to the use of treated cambric there is an extensive use of dry cloth largely in the form of tape which is afterwards varnished in place on the coil. In fact a really superior coil insulation consists of a cotton taping on which repeated dipping coats of varnish are applied, baked dry, of course, between each dip. Successive tapings with following varnish dips are used in proportion to the service voltage.

Wood—Dry wood is as good a dielectric as air and is often useful for supporting structures under oil or in clean dry locations. Damp wood is worthless for insulating purposes. The whole problem in the use of wood is to keep moisture and excessive conducting dirt away from it. Thoroughly dry wood soaked with transformer oil is almost equivalent to the oil itself but will accumulate moisture within itself or on its surface if the oil gets wet. Coating wood with a varnish helps somewhat to keep moisture out unless the atmosphere becomes very damp and a thorough impregnation with linseed oil is still more effective. Such impregnated wood coated with a smooth varnish can be used outdoors for strain insulators with a surface creepage distance of about five inches per kilovolt. It is very difficult, however, to get an impregnating compound to penetrate entirely through the structure of wood and there are always liable to be small portions unfilled.

Of course wood is inflammable and, therefore, is not looked on with favor by the Underwriters. In spite of its faults, however, its cheapness, ease of working, etc. make it desirable for special uses. In general, however, the use of wood for insulating purposes is decreasing relative to other types of material and is confined more to apparatus that operates submerged in oil.

Varnishes—It was discovered long ago that the various varnishes had insulating properties and, in addition, improved the resistance of other insulating materials against moisture, that foe of all insulation. In general, varnishes are of two classes with, of course, some varieties that are more or less intermediate. First, there are the gums or waxes which go into solution in a suitable liquid such as water, turpentine, alcohol, benzine, etc. These dissolved gums, when spread out as a varnish, release their solvents and dry as a thin film on the surface on which they are spread. Second, there are the oils which on exposure to the air take up oxygen and gradually change into a hard tough film.

To the first class belong the various waxes, gums and asphalts. For example, gum arabic and glue take up water and harden by the loss of water. Shellac dissolves in alcohol and hardens by its evaporation. Some other organic resins, such as the various gums, pitches, etc., dissolve in turpentine, benzol or other solvents. The list in this class is long and varied.

The second class is represented typically by what are known as drying oils, of which linseed oil and tung oil, more commonly known as "china wood" oil, are representatives. These oils when exposed to the air tend to absorb oxygen and congeal into a hard body not easily redissolved. It is an oil of this kind that forms the basis of most paints and high class varnishes. As a matter of fact, the greater part of the oil varnishes are a combination having some material such as copal, dammar or other fossil gum treated in such a way as to dissolve in oil and a diluting solvent such as turpentine or benzine, etc.

In drying such a varnish, the solvent passes off first, leaving a tacky film which is then oxidized to a firm, smooth, horn-like texture. Varnishes of either type are unsuited for filling the interior of coils or for any use not freely accessible to the air. If carrying a solvent, this solvent cannot escape and will boil out when the device is heated. In the case of varnish from drying oils, it is difficult for varnish in the interior to obtain sufficient oxygen to harden the oils. Any varnish remaining in apparatus in a plastic or fluid state is liable to flow out when heated and become a serious nuisance. As a medium for sealing up the outside of coil windings with a good dielectric coating, however, the high grade oil baking varnishes are excellent.

Certain oil varnishes when properly baked are oilproof when used in transformers. The same may be said of shellac and alcohol but not of materials in which benzine or similar solvents are used and there is an absence of any oxidizing oil.

In general, the baking varnishes are moisture-resistant, especially if applied in a number of coats, but cannot be said to be really waterproof. In other words, a very thorough coating of many dips of a high grade baking varnish will give a very high degree of moisture protection. Such treatment is suitable for marine motors.

As to acid and alkali, no very great dependence should be placed on any coil varnishes as to resistance to active chemicals. Very mildly acid conditions may be withstood for some time by a treatment such as above referred to for marine motors. In general, strong acids and even weak alkalies have a very deleterious effect on organic insulation. The asphalts or rubber stand up fairly well, but it is always much preferable to protect windings from chemical action either by totally enclosing the apparatus or ventilating it with clean air.

Gums, Asphalts, Pitches, Waxes, etc.—This class of materials is legion and there are also a vast number of combinations possible. To a certain degree the above names are interchangeable but not entirely. Gums are commonly of vegetable origin and are either exudations produced naturally or artifically from trees, shrubs, etc., or are extracted by a destructive distillation. Shellac, gutta-percha, gum arabic, crude rubber, chicle, etc. are examples. The so-called fossil gums were natural exudates from prehistoric trees and have been preserved in the soil for long periods. Copal, dammar, kauri, etc. are examples of these. These fossil gums or resins are more insoluble and refractory than fresher products but, when brought into solution, are a component part of high class varnishes.

Asphalts used in electrical work are usually the residual material from certain petroleums. They are black and oil soluble. They can be had of various degrees of hardness and melting temperatures. Some are plastic at normal temperature, while others are more rubberlike in character. Others may be natural residues and are mined from the earth, like gilsonite, and are brittle with a bright fracture. Various combinations of these asphalts to give proper physical and thermal characteristics are used in two ways, i.e. by impregnating coils with the melted asphalt or by applying the asphalt to the outside in a liquid form with a suitable solvent. The former method of impregnating apparatus not subject to oil with an asphalt gum is now common and has several advantages. The asphalt gum is a good insulator, it is a better conductor of heat than the air in the space it fills. It is fairly waterproof and resists chemicals and fumes. Such asphalts are used in melted form to fill cavities and seal them against moisture.

By the term "pitch" is usually meant residues from vegetable oils such as cottonseed pitch, wood pitches, etc., but coal tar residues are often referred to as pitches. They are used as ingredients in crude varnishes. One of the chief uses of pitches, however, is for binder purposes in molded insulation products.

Waxes are either of vegetable or animal origin, but usually the former. Paraffin, ceresin, ozite, beeswax, carnauba wax, halowax, etc. are examples. In general, they are oil soluble and easily melted. They are used for impregnating purposes in such things as condensers, ignition coils and similar articles where cost is not a consideration and where high fluidity in the melted condition and high dielectric strength are desired. Beeswax and rosin melted together make an impregnating material used in mica condensers and as a sealing compound for the high tension winding of certain types of battery ignition.

In general, all of the above mentioned gums, asphalts, pitches and waxes are more or less soluble in transformer oils but some combinations can be made that are practically oilproof. Such combinations, used principally for the impregnation of small transformers, usually contain linseed oil varnish residues, rosin or coal tar materials. As all are hydrocarbons, they are inflammable. There is one exception, the halowaxes are chlorinated hydrocarbons and are not at all disposed to burn.

Bakelite, Condensite, Redmanol, etc.—These are the so-called condensation products and are synthetic resins composed of phenol and formaldehyde. It is a curious fact that two organic materials, as poisonous and violent in their action on living organisms, can chemically combine into a harmless varnish-like liquid which again has the remarkable quality of hardening under heat in such a way as not to soften again, even though heated to the carbonizing or burning temperature. In the pure form these materials are used to form substitutes for amber in pipe stems, jewelry, etc. For insulation purposes, the clear varnish is used as an impregnating liquid where strength and heat-resisting qualities are desired. For example, automobile starting motors treated with bakelite do not need bonds to hold the coils in as the bakelite is amply strong for this purpose. The insulation, moreover, is waterproof for such low voltages.

The use of this synthetic varnish for treating paper or cloth which is to be bonded together into a board, tube or similar form is one of the applications to which it is particularly suited. Such board has good dielectric qualities and is of fine appearance. It can be machined, drilled and tapped, and takes a high polish. If desired, the material can be formed into special shapes and then bakelized in molds to keep such shape permanently. Such a product has been made in sizes from very small wiring supports up to Liberty airplane motor propellers.

Combined with such fillers as wood flour or asbestos, these synthetic resins make a molding mixture suited to a variety of uses. The wood flour—conden-

site or bakelite combination for example, is used for ignition distributor heads and extensively as a substitute for hard rubber. The three trade names,—Bakelite, Condensite and Redmanol—represent essentially the same product as offered by three different companies.

Rubber—Rubber while coming under the class of vegetable gums, is of such special value as an insulation and possesses such qualities as to warrant detail comment. Rubber is derived from a latex or milky juice derived from a variety of tropical trees or shrubs. Its chief geographical sources are Brazil, Africa, Central America, Java, Borneo and various other East Indian territories. Rubber is a hydrocarbon of probably several different molecular structures combined. It is very inert to chemical action in general but is soluble in certain hydrocarbons like coal tar naphtha. In general it takes a combination of two solvents to dissolve rubber properly. Otherwise, it is very resistant to corrosive materials generally.

Raw rubber is unsuited to industrial uses because it becomes comparatively brittle when cold and goes to the other extreme and becomes sticky when hot. The great discovery was made years ago by Goodyear, and afterwards by Hancock, that sulphur when incorporated with rubber would correct this evil and make rubber uniform in quality over a wide range of temperature. Ordinary elastic rubber may carry 3 to 7 percent of sulphur. Increasing the sulphur to 12 percent renders it harder but yet too flexible to be broken. At 20 percent the product is tough, but can be bent appreciably before breaking. At 28 to 30 percent the rubber becomes distinctly "hard" and is brittle but takes a high polish. The use of rubber for insulation is chiefly in three applications—cable insulation, protective and insulating bushings, molded hard rubber parts, particularly of telephone and wireless signal apparatus.

As wire and cable insulation rubber has a special value because of its high dielectric strength and its flexibility. Because of its cost, rubber for such purposes is usually loaded with various impurities such as litharge, zinc oxide, etc., to cheapen the coating without too much reducing the flexibility and insulating value. The thickness of rubber required for insulation on wires and cables varies with the size of cable and, of course, with the voltage. Ordinarily, about 3/64 to 1/16 inch is used for 600 volts. At higher potentials such as 6600 to 11 000 about ¼ inch is a common thickness. As rubber, like most vegetable gums, oxidizes in contact with air, it is bound to deteriorate with age. So far as possible its surfaces should be protected from the air and light. The effect of air and light is, as in the case of other gums, to make rubber hard and brittle and therefore worthless for electrical purposes.

Rubber for such work as cable bushings is largely being superseded by either porcelain or the various bakelite or shellac molded compositions. The objection above referred to of deterioration with age is the most serious, as such pieces are naturally exposed to the air and generally, if of soft rubber, will not last as long as the other parts of the apparatus.

For general use as hard rubber there is no material quite its equal where very low leakage is required. The only difficulty is the release of sulphur from its composition by exposure to light and air with resulting surface leakage. Rubber has a specific inductive capacity of about 2.5 but this is increased somewhat by high sulphur content to as high as 3.0.

Oils—Vegetable and Animal—Except for varnish making, there is no great use made of vegetable and animal oils for insulation. The impregnation of wood by boiling in linseed oil is a well established process and gives excellent results in removing and excluding water and afterwards holding the wood to definite dimensions and good dielectric strength. It is possible to use some of the vegetable oils for dielectric purposes but in general such oils are so much more expensive than mineral or petroleum oils that their use is not warranted except in an emergency.

Mineral or Petroleum Oil—The use of a petroleum oil to insulate and carry away the heat from transformers began about 20 years ago. As insulation, oil is excellent when dry. The presence of a very small amount of water (2/100 of one percent) will reduce insulating value by one-half from strictly dry oil. Dry oil should have a breakdown value of 30 000 to 40 000 volts for a 150 mil ball gap. A 100 mil flat surface one inch gap diameter standard gap should show 20 000 watts or above.

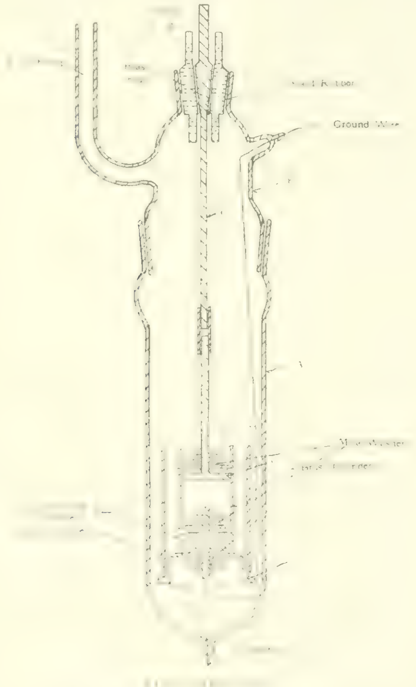
Among the problems connected with the use of oil were that of fire risk and that of "sludging" or depositing a gummy colloidal sludge on coils. The fear of fire led to the use of oils of high flash point which, however, are more viscous and have a greater tendency to deposit a sludge and thereby prevent the carrying off of heat from the copper. It has been found, however, that the relative flash points of various oils in transformers make very little difference as to fire risk. Even the most volatile transformer oil does not approach the production of explosive or inflammable vapor in the air above the oil. The flash point only becomes of consideration in case the oil becomes spilled on a warm surface with flame present, then a low flash oil will take fire and burn more rapidly than one of considerably higher flash.

For circuit breaker insulation, the requirements as to sludging and heat transference do not hold while there is distinct danger of oil being splashed in the presence of flame. A high flash oil should be used in circuit breakers and, if a non-inflammable oil should be developed, it should be used even at a cost of ten times that of ordinary oil. The specific inductive capacity of petroleum oil is between 2.0 and 2.25 and its thermal capacity per pound, or specific heat, is about half that of water. It takes one kw-min. to raise 10 gallons one degree C.

Conduction in Liquid Dielectrics

J. E. Shrader
Westinghouse Research Laboratory

IT IS well known that when a voltage is applied to most insulating materials, there is at first a flow of electricity which is large compared to the value of the current when it has reached a steady state. A part of the initial current is due to instantaneous condensive charge and a part to absorption and to conduction. The current due to absorption decays almost exponentially with time and the length of time required to reach a small part of its original value depends upon the nature of the dielectric under test. The value of the current after it has reached a steady state is due to ordinary conduction. The separation of these component parts of the current is attended by considerable difficulties.



For determining the characteristics of liquid dielectrics in a vacuum at high temperatures.

The instantaneous condensive charge prevents the study of the absorption current during the first few seconds due to the slow response of sensitive direct-current measuring instruments. Consequently only that part of the absorption current subsequent to the first few seconds following the application of the voltage, has been studied. The value of the current after a steady state is reached serves to determine, according to Ohm's law, what is ordinarily called the direct-current resistance. It should be understood in this connection that insulation resistance defined strictly by Ohm's law, is an uncertain term, since it varies with applied voltage, increasing with voltage for some materials, and for others decreasing with voltage.

For liquid dielectrics, duplicate measurements are very difficult to make. With clean electrodes the conductivity is smaller than with those that have been contaminated by use. Foreign material deposited upon the electrodes increases the apparent conductivity of subsequent samples. Hence the electrodes should be carefully cleaned for each sample. The procedure which has proven satisfactory is to dip the electrodes in benzine, followed by a thorough polishing with a linen cloth, then rinsing with ether. After rinsing with the liquid to be tested the electrodes are ready for use. To repeat results on any liquid dielectric, great care also has to be observed in taking the sample. Results will be different, depending upon whether the liquid has been shaken up before removal from the stock or

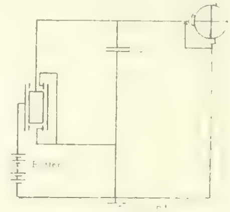


FIG. 2—TEST CONNECTIONS

whether it has been allowed to stand for some time. Also the conductivity will be different if the sample has stood for some time in the test cup before measurement rather than having been measured immediately after sampling. Repeated testing of the same sample also lowers its conductivity. The conductivity is affected quite markedly by changes in temperature so that this has to be taken into consideration. Exposure to light also increases the conductivity. If all these precautions are taken, an accuracy of five percent can be made in conductivity measurements for most liquid dielectrics.

Some liquid dielectrics have such extremely small conductivity when tested by direct-current that a very sensitive instrument has to be used to measure the current, unless the sample container is extremely large. The sample container or test cup should be of such form that all the liquid dielectric is subjected to the same electrostatic stress. This condition is best satisfied by a cylindrical test cup of two coaxial cylinders, the inner one being provided with guard rings. Preliminary measurements were made with a test cup of this type, whose inner and outer cylinders were 4 and 4.5 inches in diameter respectively, the active part of

the inner cylinder being 3.25 inches long. A galvanometer of 1×10^{-10} amperes sensitivity was used to measure the current. This arrangement was not sufficiently sensitive for all cases encountered and consequently the more sensitive electrometer method was used. By this method with a subdivided mica condenser and an air condenser of small capacity measurements could be made over a range from 1×10^{-8} to 1×10^{-15} amperes with sufficient accuracy. This method permitted the use of a smaller test-cup which could be easily enclosed for vacuum treatment of the materials under test.

THE TEST CUP

It seemed desirable to design a test cup which would meet the following requirements:—(1) Suitability for enclosure in a vacuum; (2)—Proper insulation to stand moderately high temperatures; (3)—Arrangement such that all the liquid is subject to the same electrostatic stress; and (4)—Facility of disassembly for cleaning. Such a test cup is shown in Fig. 1 in the glass vessel, *A*, suported by the rod, *C*, the upper part of which is tapered to fit the hard rubber stopper fitting into the ground joint in *B*. A spiral tungsten wire *E*, sealed into the bottom of the vessel, makes connection from the battery to the outer cylinder of the cup. The vessel can be exhausted through the tube *F*.

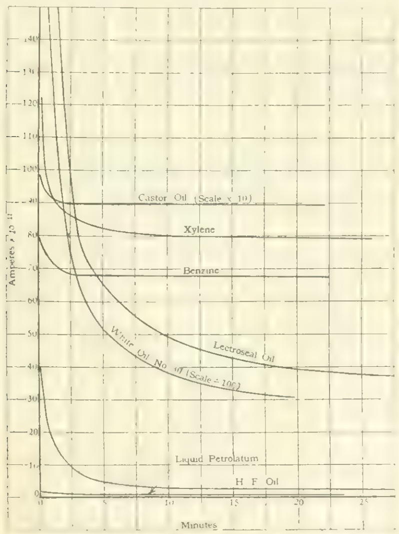


FIG. 3—CURRENT-TIME CURVES OF LIQUID DIELECTRICS

The test cup consists essentially of the two coaxial brass cylinders, *a*, of 3.54 cm inside diameter and *b*, of 2.54 cm outside diameter and 2.54 cm length with the guard rings *c* and *d*. The cylinder *A*, is fitted to *e* by a tapered ground joint which is readily separated for cleaning the surfaces. The parts *b*, *c*, *d*, and *e* are insulated from each other by mica washers as shown. The supporting part, *f*, is fitted to *b* by a tapered thread. To equalize the pressure inside and outside of *b* and thus prevent the flow of liquid through any part that could not be made perfectly tight a hole is bored through *f* and its stem, communicating by a side opening to the space outside some distance above the liquid.

The mica insulation will stand the high temperature without deterioration. The guard rings, *c* and *d*, are connected together and to ground. This form of cup subjects the whole of the sample to the same electric stress and gives a symmetrical field between *a* and *b*.

ELECTRICAL CONNECTIONS FOR THE ELECTROMETER METHOD

The electrometer used is the Compton type, having a sensitivity of 900 millimeters per volt, on a scale one meter distant. The electrical connections are shown in Fig. 2. The capacity *C* is a subdivided standard mica condenser with divisions, 0.01 to 0.5 microfarads. For very small currents this condenser is replaced by an air condenser of known capacity. The battery *B*, is made up of small dry cells of the flash light variety, each unit consisting of three cells in series. For high potential

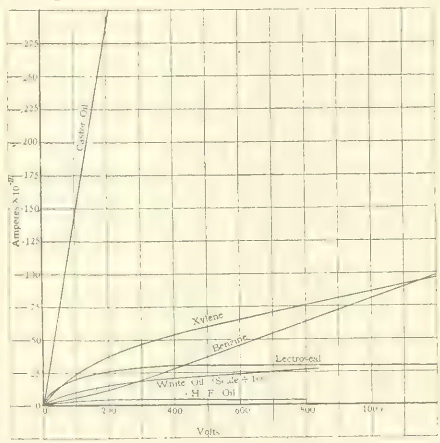


FIG. 4—EFFECT OF VOLTAGE ON CONDUCTIVITY OF LIQUID DIELECTRICS

insulation the paper wrappers were removed from these units and the whole was given an insulating coat by immersion in melted paraffin. A sufficient number of these units were assembled in boxes with suitable connections to give potentials up to 1500 volts. One terminal of this battery is connected to the outer cylinder of the test cup and the other is grounded. The key, *K*, connects the two pairs of quadrants and brings them to the same potential, one pair being permanently connected to ground. When a current measurement is to be made, the key is opened, upon which the condenser *C* and the insulated pair of quadrants receive a charge by leakage through the specimen, which raises then, in a given time, to a potential which is indicated by the deflection of the electrometer. The current is then given by the equation,

$$i = \frac{CV}{t}$$

where C = the capacity,
V = the potential as indicated by the electrometer, and
t = the time to raise the potential from O to V.

With a given potential applied to the needle the calibration of the electrometer is effected by applying a known potential between pairs of quadrants and observing the deflection. The capacity, C, includes the capacity of the condenser and that of the system, which is ordinarily so small in comparison to the capacity of the

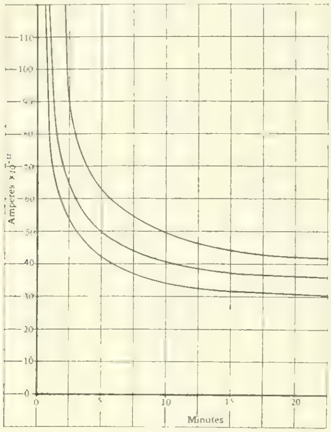


FIG. 5—DECAY CURVES OF LECTROSEAL OIL AT 800 VOLTS

condenser that it may be neglected. To protect the system from electrostatic disturbances, the test cup and condenser are placed inside a metallic lined box which is connected to earth. The wire connection to the electrometer is shielded by a brass tube connected to ground.

The question naturally arises as to whether the nature of the material of the electrodes affects the conductivity. To test this point, electrodes of brass, copper, nickel, silver, and gold were used. No difference greater than the experimental error could be observed. Many samples of the same kinds of oils have been investigated, which differ widely in conductivity. While

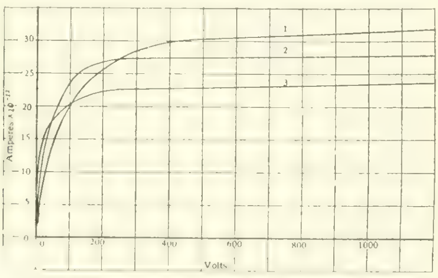


FIG. 6—SATURATION CURVES OF LECTROSEAL OIL.
1—Electrode distance 5.0 millimeters.
2—Electrode distance 4.0 millimeters.
3—Electrode distance 2.9 millimeters.

all of the same kind of liquid dielectrics have the same general properties it is practically impossible to duplicate values of conductivity on different samples until more is known about the molecular structure and the kind and amount of impurities present.

DECAY CURVES FOR LIQUID DIELECTRICS

As previously stated, when a voltage is applied to a dielectric, the initial current is greater than that corresponding to Ohm's law, and this initial current rapidly decreases to a steady value. The decay curves for several liquid dielectrics are shown in Fig. 3. Lectroseal transformer oil and white oil of paraffin have marked absorption. Liquid petrolatum likewise has

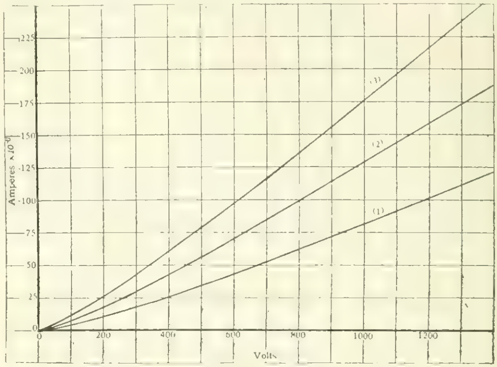


FIG. 7—SATURATION CURVES OF BENZINE
1—Electrode distance 5.0 millimeters.
2—Electrode distance 4.0 millimeters.
3—Electrode distance 2.9 millimeters.

marked absorption, the initial conductivity being more than ten times the final conductivity though this does not show in the curve because of its very low conductivity. When the potential is removed and the electrodes grounded the samples always show a reverse current of polarization due to absorption, which also decays with time. The curves given here can be repeated using a fresh sample and observing all precautions as to cleaning the test cup. The conductivity is always lower on successive tests of the same sample, probable due to the removal of impurities by the electric field.

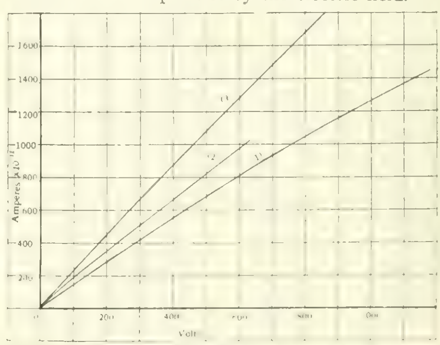


FIG. 8—SATURATION CURVES FOR CASTOR OIL
1—Electrode distance 5.0 millimeters.
2—Electrode distance 4.0 millimeters.
3—Electrode distance 2.9 millimeters.

VARIATION OF CURRENT WITH VOLTAGE

When the voltage on a specimen of some liquid dielectric is increased, there is a change in the current which is not always proportional to the voltage for all

voltages as required by Ohm's law. For smaller voltages the increase in current with voltage approximates Ohm's law but for higher voltages, for some liquids there is a falling off of the rate of increase until a voltage is finally reached where the current is practically independent of voltage over a considerable range until breakdown voltages are approached. This phenomenon is similar to the saturation current in ionized gases. For the initial voltage, longer time is required for the current to reach a steady state than for subsequent voltages. A voltage is finally reached when the current almost at once reaches a steady state corresponding to no increase in current with voltage.

In Fig. 4 the saturation effect is very clearly shown for Lectroseal and High Flash transformer oils. For benzine the current increases slightly more rapidly with increasing voltage than would be expected from Ohm's

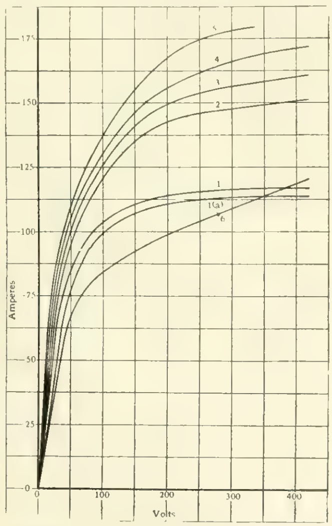


FIG. 9—SATURATION CURVES FOR VARIOUS SAMPLES OF LECTROSEAL OIL

Ordinates are "Amperes $\times 10^{-10}$"

law, which agrees with the facts found for some solid commercial insulating materials. Xylene shows a small saturation effect for the lower voltages but the current-voltage curve is practically linear above 400 volts. Castor oil shows complete absence of the saturation effect, at least up to 800 volts.

VARIATION OF CURRENT WITH DISTANCE BETWEEN ELECTRODES

Those substances showing a saturation current should, if the analogy with gases holds, show a larger value of the saturation current for the greater distance between the electrodes. To prove this, the electrode distance was decreased by fitting concentric cylinders closely into the outside cylinder of the test cup. In this manner the conductivity was determined for electrode distances of 5.0, 4.0 and 2.9 mm. Fig. 5 shows the decay curves for Lectroseal oil which Fig. 6 shows the saturation currents for the different electrode distances. The analogy with ionized gases holds for this sample, as was to be expected. For the lower voltages before saturation is reached the current varies inversely with electrode distance, but after saturation is reached, the greater the electrode distance the greater the current.

Castor oil and benzine, as seen in Fig. 4, do not show saturation effect. It is likewise the case for these samples that the greater the electrode distance the smaller the current. For these samples whose current-voltage curves are shown in Figs. 7 and 8, the resistivity as calculated by Ohm's law practically checks for the three electrode distances over the range of voltage employed.

DIFFICULTIES ENCOUNTERED IN CONDUCTIVITY MEASUREMENTS

As an illustration of the difficulties encountered in measurements in conductivity of liquid dielectrics, the series of current voltage curves for Lectroseal are given in Fig. 9. Curve *1* is for fresh oil tested in a cup which

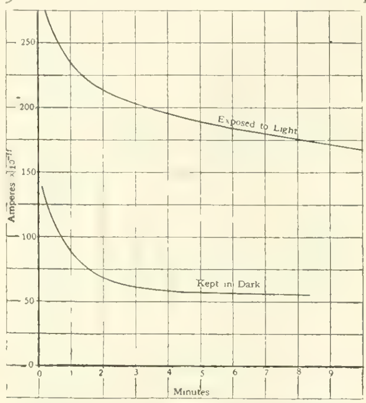


FIG. 10—ACTION OF LIGHT ON LECTROSEAL OIL

has been carefully cleaned. Curves *2*, *3*, *4* and *5* are for samples of the same oil tested in succession in the same cup which had not been cleaned after curve *1* was obtained. These show a progressive increase in conductivity due, no doubt, to a settling out under the influence of the electric field of impurities such as dust particles and minute drops of water, the greater change being for the first repetition. After the sample used in curve *5* had stood in the test cup for 34 hours the current-voltage curve was again taken. This is shown in curve *6*. During this time the settling out of the impurities from the oil had more than counteracted the effect of their collection on the electrodes. The cup was again cleaned and a new sample of the same oil gave the current voltage curve *1a*, which practically duplicated the original curve *1*, obtained under like conditions.

If samples of the same oil are taken out in separate containers and are allowed to stand for a time, accurate duplication can not always be obtained. Four glass stoppered bottles were carefully cleaned and dried in an oven and filled with oil, thoroughly mixed from the same container, and set aside under like conditions for

a few weeks, after which they were tested with the following relative values for the standard test cup.

Sample *1*—2.50 × 10^{-11} amperes.
Sample *2*—5.78 × 10^{-11} amperes.
Sample *3*—2.45 × 10^{-11} amperes.
Sample *4*—5.15 × 10^{-11} amperes.

There is a wide difference in these values, while successive tests of the oil from the original container could be made with an error of about five percent. This phenomenon is probably due to some action of the glass bottles whose chemical constitution was not the same for all.

The exposure of samples to light also greatly changes the conductivity. Two samples were prepared, one of which was placed on a table in the room, while the other was placed in a dark cupboard. The decay curves in Fig. 10 shows that the action of the light has caused considerable deterioration of the insulating properties of the oil. Similar difficulties are also encountered in other dielectric measurements. Some preliminary work on breakdown strength of oil shows that many of the same phenomena are present in such determinations.

Laminated Iron in Electric Motors

M. S. Hancock

When an alternating flux passes through an iron circuit, losses are set up in the iron. These losses can be divided into two components, hysteresis loss and eddy current loss.

To change the flux through an iron circuit slowly from a certain density in one direction to the same density in the opposite direction, and back again to the original condition requires a certain amount of energy. This energy is lost in the iron and is known as hysteresis loss. The hysteresis loss in an iron body of volume V carrying an alternating flux of frequency f and maximum density B is usually given as $K_1 V f B^{1.6}$. It is independent of whether the material is laminated or not. K_1 is a constant varying with the quality of iron used and the units used for V, B, and loss.

If any material that is an electrical conductor has an alternating flux passing through it, voltages are produced in the material itself that cause currents to flow. The I^2R of these currents forms the eddy current loss. When B = maximum flux density, V = volume of material, f = frequency, K_2 = constant varying with material and units, and L = thickness of laminations (when laminated), the eddy current loss is usually given as $K_2 V f^2 L^2 B^2$. This is when each lamination is perfectly insulated from all others. This loss depends, not on the magnetic properties of the material, but on the electrical conductivity. Different qualities of iron vary in this respect. Also it is seen that the thicker the laminations, the greater is the loss. The armature of the motor or the generator has such an alternating flux and consequently such losses.

These losses affect the heating, rating and efficiency of a motor. If the iron loss is decreased, a smaller motor may be used for a certain output at a certain temperature. Also, since the losses are less, the efficiency is higher. The iron loss is practically constant from no load to full load and so forms a constant loss to the motor user at all times the motor is running. A constant loss affects the efficiency at fractional loads much more than at full load.

Laminating the iron has no effect on the hysteresis loss. Changing the quality of iron used is the only way of reducing this loss. It is possible, however, to reduce eddy current loss by reducing the thickness of laminations, by insulating laminations more perfectly and by using iron with a higher resistance to the flow of current. Since the eddy current loss is equal to $K_2 V f^2 L^2 B^2$, if K_2V and B are constant the eddy current loss increases as the square of the frequency. To keep the eddy current loss constant the thickness of laminations should be inversely proportional to the frequency. Because of these effects thinner laminations are used for machines having a high frequency of flux in the iron than are used for those having a low or moderate frequency. Theoretically it would seem that the eddy current loss could be reduced indefinitely by reducing the thickness of laminations. Experience has shown this to be impractical past a certain point. If the lamination becomes too thin the punching tends to be drawn out of shape when the punching is large, and the burr at the edge of the punching becomes large as compared to the thickness of lamination. This results in an armature core that is not mechanically good and that again has a high eddy current loss due to the insulation between laminations being pierced by the burr.

In the case of field poles, the flux does not alternate but increases and decreases. The part of the pole face just over an armature tooth will have a higher flux density than that over a slot. This gives the same effect as an alternating flux but in a modified degree. In the early days of the electrical industry the importance of these losses and their causes was not well understood and armature cores and poles of unlaminated iron were used. Present practice is to laminate both armature core and poles, but with the armature having the thinner laminations. The steel used for the laminated parts of the motor is received at the factory from the mill in the form of large sheets, and already annealed. The annealing affects the constant K_1 and K_2, and the factory tests all shipments of such steel to see that they have the right properties.

The first operation, in the case of punchings for industrial motors, is to enamel the large sheets of steel. The sheet is run between two rolls that are kept covered with liquid enamel. This places a coating of liquid enamel on each side of the sheet. From the

rolls the sheet goes on to an endless chain which carries it through an oven. While passing through this oven the enamel is thoroughly baked on. This operation then gives large sheets of steel with insulating enamel smoothly and thoroughly baked on both sides. After enameling, the sheets are sent to the shears, where they are cut into long strips, squares or whatever form desirable before punching. From the shears the material is sent to the punch press. Here it is punched by one or more operations into the final shape of lamination wanted. If the die is made to punch the entire lamination in its final state from the plain sheet in one movement of the press, it is called a compound die. This would complete all punching on that lamination. Other type dies are sometimes used. A very ordinary type of die punches only part of the lamination, next a second die punches another part and it may require in sequence the use of a third or fourth die to complete the lamination. For example, in punching the lamination for the stator of some small induction motors the first die used punches the slots and the outside edge of the lamination. The second die used punches out the inside of the lamination. A third class of die which is used for punching slots, is the index die. In using this die the material is rotated and one slot after another is punched with the same die.

With regard to the different dies, the one selected depends on the type of punching desired and the number. If a great number are wanted the compound die is used. If a small number, the index die is used to punch the slots and other dies punch the hole for the shaft, or any other punching needed. The compound die is comparatively expensive to make and cheap to use, while the index die is cheaper to make and the cost of labor while using is higher.

In any punching operation the edge punched is always roughened slightly on one side forming a minute burr. This burr is objectionable in that it has a tendency to cut through the enamel on the adjacent lamination, thus forming an electrical contact and increasing eddy current loss. This burr gradually increases in size as the die wears. It is kept small by good care of the dies and by not using them too long. Before the burr becomes bad the die is changed. In this way the maximum size of the burr is limited. The effect of what little burr is permitted is largely overcome by assembling the laminations in the order of their punching and with the burr on all laminations pointing in the same direction. In this way the burr on two adjacent laminations is always of about the same size and overlaps; hence it does not make a good electrical connection.

Some small punchings are bumped after leaving the punch press. They are usually punchings for fractional horse-power motors. When a punching is bumped it is put in a press between two flat surfaces and pressure is applied between the two surfaces. This pressure is not high and is not for the purpose of flattening burrs but is to make the punchings absolutely flat so that they will assemble well.

The rotor of a motor may be assembled on the shaft with which it is to be used, or may be assembled on a duplicate shaft and then riveted to hold it together, or may be assembled on a spider. The second method is the most common in the assembly of industrial motors. In assembling the first step is to "count" the laminations used so as to get the number to make the proper size of core. This is sometimes done by actually counting the laminations, sometimes they are weighed to get the right number and sometimes they are assembled so as to get a certain size core before tightening up, as measured by a scale. The different methods make no difference. The aim in each is to use such a number of laminations that, when tightened up, the dimensions of the core will be correct. Having "counted" the punchings, the assembler takes them in the order brought to him, which is the order of punching, and feels each punching to make sure that the burr is on the same side on all of them. Next he puts them on the shaft, duplicate shaft or spider, as the case may be. They are lined up properly by means of the keyway and by having a wedge shaped piece of metal extend up and down the slot space. Each new punching put on the shaft must have its keyway fit over the key of the shaft and have a slot fit over the piece of metal. This lines up both slots and keyway. Heavier end plates are put on both sides of the core. The first one is put on the shaft before any of the punchings are put on, and the last after all punchings are on.

In the case of the core assembled on the shaft with which it is to be used, the core is next compressed and either pressed on a knurled shaft, in which case the press fit holds the laminations, or is put on a shaft having a shoulder turned on it and then a ring is so shrunk on the shaft as to hold the laminations solidly between the shoulder and the ring. The duplicate shaft used for assembling is threaded at the top. A nut is put on and tightened down on the end plates thus compressing this type core. While still compressed long rivets are passed through holes in the core and end plates and are then riveted down so as to hold the core together. The nut is then taken off and the duplicate shaft removed. In the case of a core assembled on a spider, the core is compressed and keys are driven in slots in the spider in such a way as to keep the core from expanding. The keys hold the end plate in place on the spider, thus preventing the core from loosening up. The slots are filed to remove the edges of any laminations that do not line up properly. This is to prevent the laminations from cutting the coil insulation. The final operations on the armature are pressing in the shaft, winding, connecting, painting, and assembling in the stator. The punching and assembling of the poles of direct-current motors is very similar to the procedure just given for the armatures.

Grounded Neutral on Alternating-Current Generators

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THERE is an increasing number of central stations operating with grounded neutral as an additional safeguard against difficulties due to abnormally high voltages resulting from line disturbances. The objections to the grounded neutral system have been that, with the neutral grounded, if another ground occurs on the system conditions equivalent to a short-circuit result, making the system inoperative, and that the resultant ground current causes objectionable telephone disturbances. With the neutral ungrounded, the system can still be operated when only a single ground occurs. Operating in this condition, however, disarranges the electrostatic balance also causes telephone disturbances and, in addition, the voltage to ground of the other two phases will be increased approximately 73 percent. If the ground is an intermittent one, high frequency oscillations will be set up, since the reactance and the capacity will be in series with each other, and may result in considerable telephone interference, generation of high voltage in the line itself and inductive disturbance in parallel power lines. Therefore, while there is the possible advantage of being able to operate a line with a single ground when the neutral is free, it must also be recognized that there are greater hazards to the system from insulation breakdowns that may result in much more serious interruptions to service.

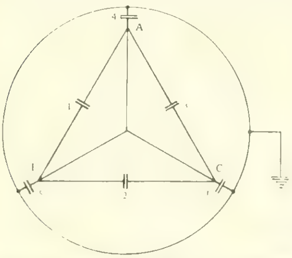


FIG. 1—CAPACITY EFFECT OF A THREE-PHASE LINE

High voltages are set up in a transmission line whenever there is an abrupt change in current or voltage with resulting change in energy conditions. Electric energy can be stored in a circuit having capacity, as in a cable system or transmission line, or can be stored in the magnetic field surrounding the conductor. High potential always has its source in the inductance of the circuit and will never be set up by capacity alone. Capacity, however, is instrumental in the generation of high voltage, since energy stored in the capacity may be discharged through the inductance. A circuit containing both inductance and capacity is much more susceptible to high voltage disturbance because the natural frequency of such a circuit may be much higher than the normal frequency and consequently the voltage set up in the inductance will be higher because of the high rate of change of the current. Also such a circuit will set up high voltages inductively in neighboring circuits.

Changes in energy conditions in a transmission system occur at times of switching, short-circuits, grounds and lightning discharges. When a circuit is closed, energy is stored in the magnetic field with increasing current and in the dielectric field with increasing voltage and when the circuit is opened this energy must be dissipated when the current and voltage decrease. A familiar example of switching is the opening of a field on a generator or motor. Energy is stored in the field equal to $0.5\ LI^2$, where L represents the inductance and I the current. When the circuit is opened, the current begins to fall and the change in energy in the short time dt equals $Lidt$. This change in energy is expended in loss in the copper and arc and is equal to $eidt$. The equation can, therefore be written,—

$$Li\ di = e\ i\ dt,$$

$$\text{or, } e = L\frac{di}{dt}$$

Where $\frac{di}{dt}$ represents the rate of change of the current. It is evident, then, that the faster the current changes the greater the voltage e will be. This example is somewhat analagous to that of a moving body being brought to rest. Here the stored energy is equal to $0.5\ MV^2$ and, if the body is brought to rest by a force acting through a space, the shorter the distance is made the greater the force must be. In a similar way, if the energy conditions in an electric circuit are suddenly changed high voltages are likely to arise.

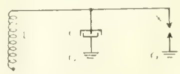


FIG. 2—EFFECT OF GROUNDS

FIG. 3—GENERATOR CONNECTIONS

In general, switching causes harmful disturbances only when the circuit is not positively closed or opened or when all phases are not closed at the same time. If an arc is formed at the time of switching and then goes out and forms again so that the circuit is opened or closed not once but a number of times in quick succession, a whole train of energy changes results which, because of their high frequency, set up high voltages at points of inductance. If all three phases do not close at the same time, a disturbance is set up due to change in the charging conditions of the line. With the general use of oil switches, disturbances from switching are reduced because, with an oil switch, the arc usually does not reform when the current goes through zero, due to the action of the oil and thus all three phases are

opened or closed together. Grounding the neutral of the system will prove beneficial in case of improper action of the circuit breaker, because the voltage of the neutral will be definitely fixed at ground potential and therefore any voltage surge will be limited to a definite value above ground voltage.

The second source of disturbance, a single-phase or polyphase, short-circuit, will produce high voltages because there is a sudden change of energy with the abrupt change of current. There is not only the change in load current, but also a change in charging current which may produce oscillations of high frequency and so cause breakdown. Here again, the advantage in having the neutral grounded is in holding the neutral at ground potential.

In both cases, if the system is fed through step-up transformers, the neutral can be grounded on the high-voltage side of the transformers. If the generator feeds directly to the line the neutral should be grounded.

Grounds on the system seem to be the most common source of disturbance. Capacity effect in a transmission line, whether a cable or aerial system, without neutral grounded can be illustrated in a diagramatic way as in Fig. 1 where *OA*, *OB* and *OC* represent the three line voltages, the condensers *1-2-3* represent the capacity effect between lines and condensers *4-5-6* the capacity effect between lines and ground. If a ground occurs on a phase *B*, the condenser *5* is discharged and at the same time the voltage to ground on phase *A* & *C* is raised $\sqrt{3}$ times. Consequently the charging current on lines *A* and *C* is increased and on line *B* is decreased to zero. The fact that the rate of change of charging current is so rapid explains the high voltage which may occur at points of inductance.

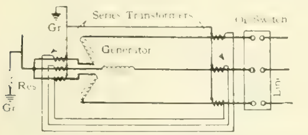


FIG. 4—CONNECTION OF DIFFERENTIAL RELAYS

Two types of phenomena now arise, depending upon whether the accidental ground holds on or whether it is interrupted and then strikes again. In the first case, conditions become settled in a short time and the only effect is telephone disturbance due to unbalanced charging current. In the second case, a whole train of disturbances is set up every time the ground strikes and these oscillations, being superimposed one on another, may result in very high voltages.

A ground on a cable in a system consisting partly of overhead and partly of underground lines is likely to be very harmful if the neutral is not grounded. The conditions existing in such a circuit can be represented as in Fig. 2 where *L* is the inductance of the line and generator, *C* the capacity of the cable to ground and *G* is the ground. When a ground occurs, as at *X*, the energy stored in the capacity of the cable to ground is dissipated through the arc and, as the energy is discharged, the current falls, the arc goes out and the capacity of the cable is again charged and the cycle repeated. The frequency of these oscillations is determined by the relation of inductance and capacity and is expressed as $f = \frac{1}{4\pi\sqrt{LC}}$. This frequency may be many times that of the normal frequency of the circuit and the result is very high voltages at points of reactance, such as the end turns of transformers or generators. This high rate of change of current will induce high voltages in the other phases in the cable and break them down to ground and result in a short-circuit. If the neutral of the system is grounded, however, the current which will flow through the accidental ground will be a dynamic one and of sufficient volume to make the ground permanent. There will not be a train of oscillations set up and the circuit breakers will usually be tripped out before a short-circuit between phases occur.

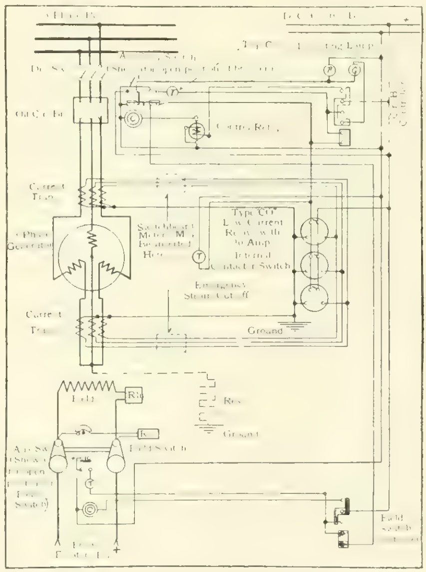


FIG. 5—DIFFERENTIAL RELAY AND AUXILIARY CONNECTIONS

Grounding the neutral will not protect the generator against damage from lightning because a lightning disturbance is of such high frequency and steep wave front that the end windings will break down to ground before relief can be obtained.

METHOD OF GROUNDING THE NEUTRAL

The generator may be connected directly to the line or through step-up transformers. In the latter case, if the neutral of the transformer is grounded, the generator will be sufficiently protected against line disturbances, but it is desirable to ground the generator neutral also to protect the machine against grounds within the machine or in the leads between the machine and the transformers. The usual arrangement for this case is shown in Fig. 3 where *G* is the generator *S* a non-automatic oil switch, *B* a bus and *T* the step-up

transformers. The wiring between the switch and the bus and transformers is generally short and can be substanially installed so that there is little chance of grounds and no protection is therefore needed.

The Merz-Price system is a differential scheme of protection used to protect a generator from grounds in itself or the leads connecting it to the bus, and for this all six leads (both ends of each phase) are brought out as in Fig. 4. In each of the three neutral leads, a series transformer is connected and the neutral leads are then connected to ground through a resistance. At the ends of the leads near the switch, three other transformers are put in and the secondary of each is connected in series with secondary of the series transformer in the neutral of the same phase. The relay is placed across the secondary leads. If a ground develops in the winding or leads, there will be unequal currents in the two secondaries of a phase and the difference in current will flow through the relay and trip the circuit breaker.

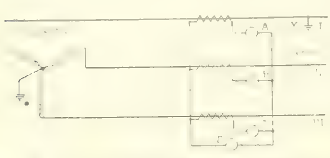


FIG. 4—RELAY PROTECTION FOR A HIGH RESISTANCE NEUTRAL GROUND

A more detailed sketch of such an arrangement is shown in Fig. 5 which provides for cutting off steam from the turbine, opening the main line circuit breaker and opening the field. The resistance can be made high, thus limiting the current which can flow to a ground and so reducing very considerably the damage that can be done. In case of a ground in the generator winding, for instance, it would be quite possible to get the machine off the line without any damage from fire outside the grounded coil. Without the neutral grounded, a single ground might not be noticed but, with the development of a second ground, the entire winding might be destroyed and possibly part of the iron. Therefore, grounding the neutral in conjuction with the differential method of protection will mean a big saving in time and expense of making repairs in case of a ground. When the generator is connected directly to the line, without first going through transformers, two cases arise in methods of grounding the neutral, dependant upon whether the grounded neutral is to be applied on a system already in operation or on a new system. The difference in application in these two cases is in the amount of resistance used in the neutral and the means taken to open the circuit breakers.

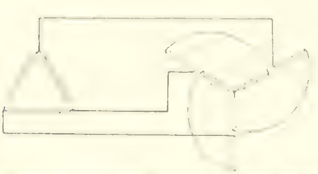


FIG. 7—METHOD OF GROUNDING A DELTA GENERATOR

With a grounded neutral, a ground on the system is a short-circuit, so that resistance is put in the neutral to limit the current which can flow at the time of a ground. On a system already installed and where it is not desirable to change the existing relay system, sufficient resistance is put in the neutral to limit the current, in case of a ground, to approximately twice the current rating of the heaviest feeder. This will give sufficient current to operate overload relays and still not give a current so large as to cause overload on the circuit breakers, distortion of machine windings, movement of feeders, or too great an arc at the point of the ground. Also, if the current is kept within reasonable limits, too great voltage drop will be prevented and synchronous apparatus is not so likely to fall out of step. Usually such a system has only two relays *A* and *C*, Fig. 6, to protect against overload and therefore, when the neutral is grounded, it is necessary to add the relay *B* to protect the third phase.

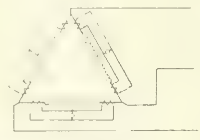


FIG. 8—DIFFERENTIAL RELAY CONNECTIONS FOR A DELTA GENERATOR

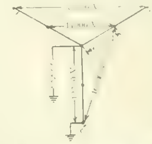


FIG. 9—EFFECT OF GROUND ON AUTOTRANSFORMERS

On a new system or one where a change in relay equipment may be made, much higher resistance can be used in the neutral by using a relay scheme as in Fig. 6. Lines *I*, *II* and *III* are three lines of a three-phase system. Relays *A* and *B* are two overload relays to open the circuit breaker in case of overload and relay *D* in the neutral is to open the circuit breaker in case of ground on one of the feeders.

If a ground occurs on line *I* at *X*, the sum of the currents in the series transformers *II* and *III* will no longer equal the current in line *I* and the difference in current will flow through the neutral relay *C* and trip the circuit breaker. The value of this ground current can be made relatively low by inserting high resistance in the generator or step-up transformer neutral, whichever the case may be. Such an arrangement will eliminate the possibility of damage from heavy short-circuits. The only limit in the magnitude of the neutral resistance is that this resistance must permit the draining of the static current from the the line.

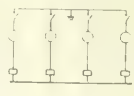


FIG. 10—PARALLEL OPERATION

The difference then in the two methods of grounding is that the first makes use of the ordinary overload relay for opening the circuit breaker in case of a ground, while the second separates the action of overload and ground on different relays and can therefore rely on a much smaller ground current for opening the circuit breaker.

In cases where a neutral cannot be obtained, such as in delta connected generators or transformers, use can be made of zig-zag transformers connection as in

Fig. 7. The Merz-Price system can be applied to a delta-connected machine by bringing out all six leads as in a star-connected machine, connecting a series transformer on each end of the phase and then making the delta connection as in Fig. 8. The system of course must be grounded by using some such scheme as the zig-zag transformer. A neutral ground can also be obtained with three potential transformers and connecting their high voltage sides in star and grounding the star point. The secondaries are connected in delta across one corner of which is placed the relay. When a ground occurs, the current in the three phases is no longer balanced and current flows in the delta secondary, through the relay and taps the circuit breaker.

To specify the resistance required in the neutral, it is necessary to know the characteristics of the system. Where the overload relays are to be used to open the circuit breakers in case of a ground, the ground resistance should equal, [illegible] The carrying capacity of the resistance should be such as to carry the ground current from 30 to 60 secondaries. This resistance in most cases has a value between 2 and 5 ohms, depending upon the size of the system. In those cases where special means are used to take care of grounds and which do not make use of the overload relay, the resistance in the neutral may be made quite high, in the neighborhood of 100 ohms.

If the system is grounded through autotransformers, it is necessary to have the neutral solidly grounded without any resistance. If, as shown in Fig. 9, an 11 000 volt machine is connected to a 22 000 line through autotransformers and the neutral is grounded through a resistance, the voltage of the neutral will be raised to approximately 12 700 volts when a ground occurs on the 22 000 volt system. This would raise the terminals of the 11 000 volt system to 16 500 volts above ground instead of 6350 volts and subject the apparatus to unnecessary voltage strain.

Where several generators are operating in parallel as shown in Fig. 10, only one machine should be grounded at a time. This can be done by connecting the ground resistance to a bus and then connecting one machine to the bus through a disconnecting switch. If all the neutrals are joined to a common bus, large circulating currents are likely to occur due to the difference in wave form of the different generators.

Grounding the neutral will not eliminate all the troubles arising from line disturbances, but will act as additional insurance against breakdown. The experience of operators who have been using the grounded neutral would indicate a very considerable benefit from its use, although it is not always possible to furnish definite figures to prove this.

It is not necessary to ground small low-voltage systems, as the amount of stored energy is relatively small and the possibility of voltage disturbance remote. For instance, a small industrial plant operating at any voltage up to 2400 volts would not require a grounded neutral. Systems operating at over 4000 volts and using generating units of 5000 k.v.a. and over should be considered as instances where grounding the neutral will be beneficial.

Heavy Alternating-Current Conductors

K. C. Randall

That the inner portion of a solid conductor is of little use with alternating currents, especially at higher frequencies, is common knowledge. That a subdivision of the conductors as approximated in ordinary stranded cable offers somewhat better conditions, especially if the individual strands are in poor contact one with another, is also generally understood. Some special construction whereby all the elements of the total conductor are caused to average the same position throughout the total length and also all have the same resistance, would afford a quite perfect theoretical solution and bring the alternating-current conductor to practically the same basis as obtained with direct current. In practice, no such construction is attained, and generally this fact offers no serious disadvantage.

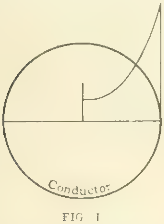


FIG. 1

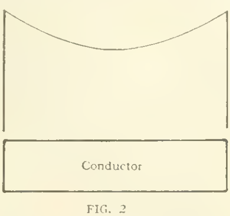


FIG. 2

In very heavy alternating-current work, particularly as found around electric furnaces, where several thousand amperes at perhaps 60 cycles have to be carried for some distance, the problem of current distribution throughout the conductor is one of the principal factors in determining the total conductor design, and may even vitally concern the construction of the supply transformers and the furnace itself.

Fig. 1 shows how the alternating current distributes itself in an ordinary circular conductor and Fig 2 is for the usual heavy bus arrangement. From both of these figures it is apparent that the inner portion of conducting material is of comparatively small value, and that the outer portion carries by far the greater current density. Fig. 3 illustrates the current distribution in adjacent conductors due to the influence of one upon the other, and here again—as in the single conductor—the current density throughout the conductors is not uniform and, therefore, the material is not used to a maximum advantage. A method is proposed for largely overcoming this difficulty and causing a more uniform current distribution to obtain throughout the parallel alternating-current conductors:—

To take care of the defects with the individual conductor, a tubular construction is used, i. e., the center of the conductor, which is of relatively little value, is eliminated. The surface of this tubular conductor is subdivided, so that its several elements may be caused to average the same relative position with regard to the adjacent parallel conductor that influences the current distribution in it.

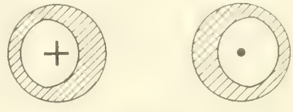


FIG. 3

This will be accomplished by using a considerable number of relatively small cables insulated from each other and distributed uniformly over the periphery of an imaginery tube throughout the length of the run, at each end of which they are fastened to circular terminals. The conductor runs should be given a twist of 360 degrees, or some multiple of 360 degrees, so that each individual cable will average the same position and have the same resistance as each other cable element. In this way there will be no choice in the paths for the current, or in other words, the impedance of each path will be the same and therefore a uniform current distribution will result.

Calculating Short-Circuit Currents in Networks

Testing with Miniature Networks

W. R. Woodward

IN THESE days of extensive and interconnected power systems it is increasingly important and difficult to estimate the effect of short-circuits at various locations in the system. Such information is essential, however, to insure the proper functioning of circuit breakers and relays, and failure to properly analyze the effects of short-circuits at various points on the system may lead to serious breakdown.

In general, calculations for determining short-circuit currents are fairly simple. There are cases, however, especially where several power houses or synchronous substations are connected to a system, where calculations are very lengthy and in a few cases practically impossible. For this reason some approximate method of obtaining current values is very desirable from the standpoint of economy in both expense and time.

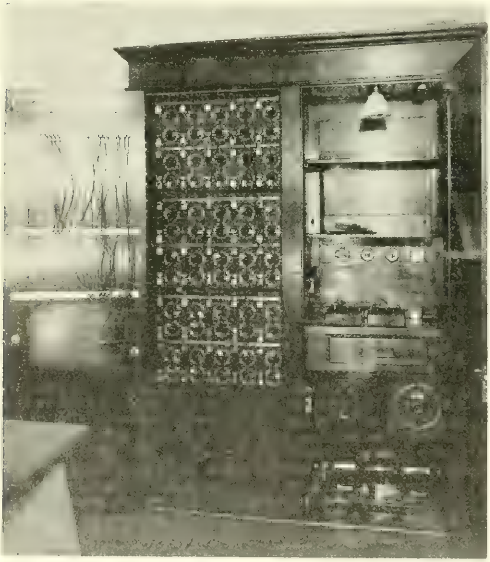


FIG. 1 TEST BOARD SET UP FOR SOLVING A PROBLEM

A flexible adjustable net work on a small scale can be used to advantage. For exact work this would necessarily include resistance, reactance and capacity units, but if this were done it would be extremely complicated and expensive. A net work involving only resistance which may be substituted for impedance or reactance, while it will not give exact results, is adequate for most cases and allowance can be made in most any problem where such a device is necessary, for the errors that are introduced by the neglect of the other elements.

In general, synchronous machines, transformers and aerial lines have similar impedance characteristics; that is, the reactance value is large with respect to the resistance value. If these impedances have exactly the same characteristics, it is obvious that if resistance be substituted for impedance and direct-current voltage applied, the current flowing will be exactly proportional to the symmetrical alternating current which would flow in the case of short-circuit. If these characteristics are not the same, some error is introduced. In most power systems, the worst case of error is where underground, three-conductor cables are used, in which case the reactance value is low in proportion to the resistance value. The net work, however, can usually be checked quickly to determine whether an incorrect impedance in these lines would merely change the total current, or would change the distribution of the current in the net work. In the latter case it might lead to considerable error, but in general the effect of the cable impedance is rather small in those short-circuit conditions which are the determining factors in apparatus application.

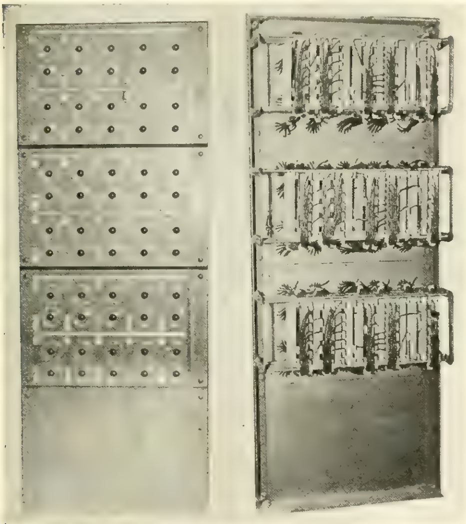
For calculation of regulation a device using resistance only can seldom be applied without more resultant error than can be allowed. For regulation problems it is usually necessary to get results within a small limit of error, whereas greater limits are permissible in estimating short-circuit values of currents. Also in the case of transmission lines the value of capacity must be considered in figuring regulation as it has a marked effect on regulation but a much less effect on short-circuit currents, as when a short-circuit occurs, the voltage between wires or from wires to ground is much reduced.

A calculating equipment of this nature recently developed is illustrated in Figs. 1, 2 and 3. This equipment contains 30 adjustable resistors mounted on a panel of three frames, with 10 units per frame. Each resistor of 1100 ohms is made in two parts, each connected to an 11 point dial. The main dial gives resistance values of 50-100-200-300 etc., to 1000 ohms, and is connected in series with an auxiliary dial which is adjustable from 0 to 100 ohms in steps of 10. By the use of these two dials any resistance from 50 to 1100 ohms can be obtained in steps of 10.

Each of the three panels of ten units were made duplicates for simplicity of manufacture. The units are mounted in two horizontal rows of five units each. A bus bar is provided at the top and bottom of the top row, and at the top only of the bottom row. Each resistor ends at a terminal block which may be connected to the bus by means of a taper plug. Several tapered holes are also provided in each terminal and bus-bar for the insertion of jumper plugs. Each bus-bar is

divided into two parts which may be connected by a taper plug and two adjacent bus-bars may also be connected by the insertion of a plug. One section of the top bar is permanently connected to the positive generator lead and the negative lead of the generator is connected to the negative bus, which for convenience is placed at one side and extends from the top to the bottom of the board.

Power for this outfit is supplied from a 500 watt, 120 volt motor-generator set arranged so as to obtain 50, 100 or 120 volts at any current up to five amperes. A low reading ammeter is arranged with flexible leads so that it may be readily connected in series with any



FIGS. 2 AND 3—FRONT AND REAR VIEWS OF RESISTOR PANEL

resistor. For this purpose the lower terminal of each resistor is split into two parts connected by a taper plug around which the ammeter may be shunted. Owing to the high resistances used, the contact resistance and ammeter resistance are negligible. The complete panel is mounted in a wooden cabinet for protection, the small motor-generator set and field resistance boxes being mounted under the instrument table.

In the application of this outfit to a net work problem, it is necessary first to reduce the impedance of every circuit to ohms. For three-phase systems this impedance should be the equivalent impedance from line to neutral. For convenience this value in ohms is multiplied by some factor M to obtain values in the range of 50 to 1100. The circuit is then set up and the dials adjusted to their proper value. By applying direct-current voltage and measuring the current in the various branches a value proportional to the alternating-current is obtained. This value, multiplied by a factor K, gives the value of symmetrical alternating current, where

$$K = \frac{A.C.\ volts\ to\ neutral \times M.}{D.C.\ volts}$$

To obtain the symmetrical current values at various time delays after short-circuit occurs, it is necessary to apply time decrement curves. These curves* are usually plotted for various values of total reactance expressed in percent. The proper reactance value to use is determined as follows:—

Let I equal the full-load current of the synchronous machines contributing to the short-circuit, and I^1 the short circuit current as obtained above. Then

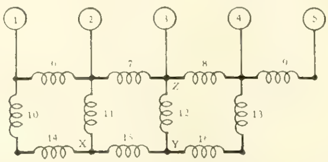


FIG. 4—TYPE OF NETWORK FOR WHICH REPEATED SOLUTIONS ARE LIKELY

$I \div I' \times 100$ equals the percent reactance of an equivalent generator producing the short-circuit current I'. Using the curve plotted for this value of reactance, the current flowing may be obtained from the curve for any time delay desired.

In Fig. 4 is illustrated the kind of case in which this equipment is very useful. In this problem the current in all branches, as well as the total short-circuit current, were desired with short-circuits at points X, Y, and Z. An engineer, after spending about a day, obtained by calculation one value of total short-circuit current. After that it was deemed desirable to have the circuit "set up" using resistances and obtain values of currents in all branches. With this equipment the same results were obtained in a few hours covering all of the necessary work of set up and checking.

*See article on "Design and Selection of Oil Circuit Breakers" by J. N. Mahoney in the JOURNAL for Sept. 1918, p. 387; also paper by Messers Hewlett, Mahoney and Burnham *Proc. A. I. E. E.* February 1918.

Analytical Solutions

ROBERT D. EVANS

THE KNOWLEDGE of the methods of solving a network of power circuits is a matter of great interest to the electrical engineer, as the solution of the network determines the maximum rupturing capacities demanded of circuit breakers,and also determines maximum stresses that may be imposed upon generators, transformers and reactors. In addition to obtaining the solution of the network under the condition of short-circuit, it is frequently necessary accurately to predetermine the performance of the network under some particular load condition, so as to obtain regulation, division of current, transmission efficiency

and selective operation of relays.

A solution of the network can be obtained either by calculation or by experiment on a miniature network. The latter method affords a convenient solution of those networks in which the impedances of all the branches are of the same power-factor. In this

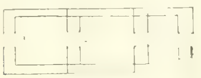


FIG. 1


FIG. 2

case the miniature network is composed solely of resistance branches, and the resulting testing table is compact, inexpensive and easy to build. Such testing tables are very convenient for the solution of direct-current net-works, and for the determination of short-circuit currents on alternating-current networks, where the resistance is negligible compared to the reactance. With networks in which the impedances are not of the same power-factor, which is usually the case with alternating-current systems, the testing table becomes quite involved because of the complication required to represent both resistance and reactance in each branch. The effect of changes in the impedances of the different branches is more easily obtained on a miniature network than would be the case if the solution were obtained by calculation. The disadvantages of the method of solution by the miniature network are the initial cost and the fact that these testing tables are not always available. Hence, the solution by calculation will remain the more important method.

KIRCHHOFF'S LAWS

Any network may be solved by setting up the equations of the circuits in accordance with Kirchhoff's Laws, which may be stated as follows:—

1—The sum of the currents about any point is zero.
2—The sum of the voltages about any closed path is zero.

A solution of these equations is usually obtained by the method of determinants. In case of a complicated network, it is sometimes difficult to set up the necessary number of equations which are independent. A useful device to avoid this trouble, due to Maxwell, is to assume that an imaginary current is circulating in a counter-clockwise direction in each mesh of the network. This device also insures the setting up of the

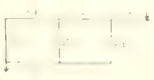


FIG. 3


FIG. 4

equations with the minimum number of unknowns. This method is probably best for a solution in general terms, that is, in letters instead of numbers. The solution of networks with numerical values by this general method is frequently very laborious and difficult to check. The purpose of this article is to show how the network may be simplified and how certain devices, based on Kirchhoff's Laws, can be used to simplify the calculations and to render checking easier. In the solution of the more difficult networks, that method of solution which permits easier checking is of the greater importance.

SETTING UP THE NET WORK

The impedance of each branch of the network should be calculated and expressed in terms of one voltage, so that a one line diagram may be drawn. If the network involves a transmission and distribution system, such as shown in Fig. 1, the impedances in the high voltage system may be expressed in terms of the low voltage by dividing the actual impedances by the square of the ratio of transformation of the step-down transformers connecting the two systems. Figs. 1, 2 and 3 show successive steps in setting up the network; Fig. 1 giving the wiring diagram of the network; Fig. 2 being a one line diagram; and Fig. 3 being a working diagram for use in the actual solution of the network. In Fig. 3 Z_1 Z_2 and Z_3 represent the transformer impedances of substations *1*, *2* and *3* respectively; these impedances are expressed in terms of the distribution voltage. Z_4 and Z_5 represent the high-voltage transmission impedances per section, expressed in terms of the distribution voltage Z_6 and Z_7 represent the low voltage

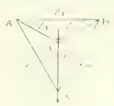


FIG. 5


FIG. 6


FIG. 7


FIG. 8

transmission impedances per section. Z_8 is an impedance which consists of generator and step-up transformer, and is connected in series with the remainder of the network. The source of power and the point of load are usually indicated by arrows as shown.

Another case, and one frequently met in practice, is that of several generators connected to a distribution system. In general, these generators may have various phase relations, but it is usually desirable to consider the generator voltages in phase and then the method shown in Figs. 4 and 5 may be used. In solving a three-phase system, it is usually preferable to use the "line to neutral" method. Fig. 4 shows a three-phase system with three generators connected to a ring bus with reactors in each section of the bus, with a three-phase short-circuit at the point *X*. Fig. 5 shows a working diagram of this network where Z_1, Z_2 and Z_3 represent the generator impedances Z_4, Z_5, Z_6 represent reactor impedances.

SIMPLIFICATION OF THE NETWORK

Having made a working diagram of the network, the next step is to simplify it so as to reduce the numerical calculation. The methods given below, when applied to some networks, will effect a remarkable reduction in such calculations. Impedances

which are connected in series should be replaced by one impedance equal to the sum. Frequently an examination of the network will show that, because of the symmetry of the arrangement, two points are of the same potential; these points should be connected together. Again, any branch can be eliminated which either carries no current due to the symmetry of the network or negligible current due to its very high impedance. For example, in Fig. 5 if $Z_1 = Z_2 = Z_3$ and $Z_4 = Z_5 = Z_6$, with the short-circuit at the point X it is evident that the points A and B will be of the same potential and can be connected together, and that the branch Z_4 can be eliminated. The network can now be drawn as shown in Fig. 6.

PARALLEL IMPEDANCES

If several impedances are connected in parallel between two points, they can be replaced by one equivalent impedance Z_0 which can be calculated as follows:—

$\frac{1}{Z_0} = \frac{1}{Z_1} + \frac{1}{Z_2} + \frac{1}{Z_3}$ etc., where Z_1, Z_2 and Z_3 etc. are the values of the individual impedances. For the important case of two impedances in parallel the equivalent impedance is equal to the product of the impedances over the sum, that is:—

$$Z_0 = \frac{Z_1 Z_2}{Z_1 + Z_2}$$

The total current I_0 flowing through the two impedances in parallel divides in inverse proportion to

FIG. 9

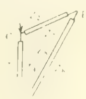


FIG. 10

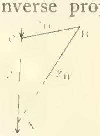


FIG. 11

the impedances, that is, the current I_1 flowing through the branch Z_1 is

$$I_1 = \frac{Z_2}{Z_1 + Z_2} \times I_0$$

Many networks can be solved by using this method. Applying it to the network shown in Fig. 6, it is reduced in steps as shown by Figs. 7, 8 and 9 to a single impedance Z_0. From Z_0 the total symmetrical short-circuit current I_0 can be calculated. The maximum current supplied by the adjacent generator is,—

$$\frac{Z_8}{Z_8 + Z_3} \times I_0$$

The maximum current flowing through the reactors and each of the other generators is,—

$$\frac{Z_3}{Z_8 + Z_3} \times \frac{I_0}{2}$$

STAR-DELTA METHOD

When the above methods have been applied and the network is still rather complicated, the next step is to replace certain groups of impedances by a group of equivalent impedances. Three impedances connected in star may be replaced by three equivalent impedances connected in delta.* Similarly, three impedances connected in delta may be replaced by an equivalent group of three impedances connected in star. In Fig. 12 three impedances are connected in star between terminals *1*, *2* and *3*. Fig. 13 shows three equivalent impedances connected in delta between the same three terminals. If the equivalent group of delta connected impedances will

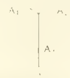


FIG. 12

FIG. 13

give the same value of impedance between the terminals *1-2*, *2-3* and *3-1*, it is evident that the delta group is equivalent to the star group. To meet the above conditions the following equations must be satisfied:—

$$A_1 + A_2 = \frac{B_1 (B_2 + B_3)}{B_1 + B_2 + B_3}$$

$$A_2 + A_3 = \frac{B_2 (B_1 + B_3)}{B_1 + B_2 + B_3}$$

$$A_1 + A_3 = \frac{B_3 (B_1 + B_2)}{B_1 + B_2 + B_3}$$

In case the impedances of the delta group or of the star group are known the impedances of the corresponding star or delta group can be calculated and the equations are as follows:—

Equivalent Star Group—

$$A_1 = \frac{B_1 B_3}{B_1 + B_2 + B_3}$$

$$A_2 = \frac{B_1 B_2}{B_1 + B_2 + B_3}$$

$$A_3 = \frac{B_2 B_3}{B_1 + B_2 + B_3}$$

Equivalent Delta Group—

$$B_1 = \frac{A_1 A_2 + A_1 A_3 + A_2 A_3}{A_3}$$

$$B_2 = \frac{A_1 A_2 + A_1 A_3 + A_2 A_3}{A_1}$$

$$B_3 = \frac{A_1 A_2 + A_1 A_3 + A_2 A_3}{A_2}$$

The above equations may be expressed in a form which is easy to remember, as follows:—The equivalent star impedance is equal to the product of the adjacent delta impedances over the sum of the impedances. The equivalent delta impedance is equal to the sum of the products of the star impedances taken two at a time divided by the impedance of the opposite branch. The

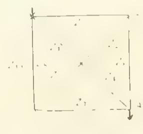


FIG. 14

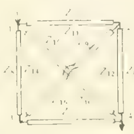


FIG. 15

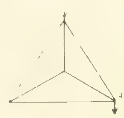


FIG. 16

substitution of the equivalent delta group for the star group is the method that is usually found more expedient. This method is, in connection with the method of parallel impedances, will solve a very large variety of networks. To illustrate how this method can be applied, refer again to Fig. 5, and assume that all the im-

*This method was first proposed by A. E. Kennelly, in an article on "The Equivalence of Triangles and Three Pointed Stars in Conducting Networks", *El. World and Engr.*, Sept. 16, 1899, Vol. XXXIV, p. 413.

pedances are of different values. In this case the points A and B cannot be tied together nor the branch Z_4 eliminated. The three impedances Z_1, Z_4 and Z_5 connected in star between the points B, C and X, with star point at A, may be replaced by an equivalent delta group of three impedances Z_7, Z_8 and Z_9, connected between these same points, as shown in Fig. 10. The impedances in parallel may be replaced by their equivalent impedances, as shown in Fig. 11. The network has now been reduced from a three mesh network to a single mesh, and the network may be solved in the manner which has already been indicated.

Perhaps it should be pointed out that it is not permissible to substitute a group of delta connected impedances for a star group when more than three impedances are connected to the star point.

The above method can be extended so as to replace a group of four or more impedances connected in star by other groups of impedances, but the simplicity of the star-delta transformation is not obtained. The minimum number of impedances required to represent a group of impedances connected between N points is $0.5\ N\ (N-1)$. The transformation formulas become very complicated unless all the impedances in the star group are equal, in which case each member of the equivalent group of impedance is equal to the star value divided by N. When this method can be used, there

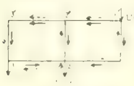


FIG. 17

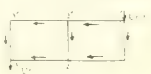


FIG. 18

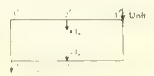


FIG. 19

is considerable advantage in doing so; for example, in the network shown in Fig. 14, the four impedances Z_1, Z_2, Z_3 and Z_4 connected between points *1*, *2*, *3* and *4*, may be replaced by six impedances Z_{11} to Z_{16}, as shown in Fig. 15. The impedances which are connected in parallel may be replaced by their equivalent impedances and the network can be drawn as shown in Fig. 16. The network has thus been reduced from six to three meshes, and may be further reduced by the star delta method, as explained above.

SUPERPOSED SOLUTIONS

Superposed solutions are particularly applicable to linear networks, i.e. with meshes connected as links in a chain, and to those problems which require a solution for every load point. In this method the principle of unit current is employed. The advantage of using unit current is that the division of current can be found and then by adding the voltage drops along any line between the source and the load point, the impedance of the network is obtained. Suppose for example, that the network shown in Fig. 17 is chosen with a load of unit current drawn from the point *2* supplied from the point *1'*. The division of currents in the different branches can be obtained by the simple device of combining parallel impedances. The division of current for this condition of load may be indicated by solid arrows as shown in the diagram. If unit current is supplied to the network at the point *2*, and withdrawn from it at the point *3*, thedistribution of current may be obtained in a similar manner and will be as shown by the dotted arrows. These two solutions may be superposed and the currents in the different branches added, and this leaves a load of unit current supplied to the point *1'*, and unit current withdrawn from the point *3* as shown in Fig. 18. By this means the division of load for a unit current at the point *3* is obtained and the impedance of the network to the point *3* can also be obtained by adding the voltage drops along any of the paths between the source and the point *3*. This method has an advantage over the method of substitution of equivalent groups of impedance as given above, in that the network is not altered and that one superposed solution may be added to another so as to solve any linear network regardless of the number of meshes.

This method has a further advantage in that the impedances for the calculation of voltage regulation are easily obtained. After obtaining the distribution of current it is an easy matter to find the voltage drop between the source and any particular point, say B, with the load at any point, say A. It is evident that the drop at B is proportional to the current taken at A, and therefore the ratio between the voltage drop at B to the current causing it should be considered as an imped-

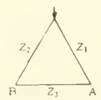


FIG. 20

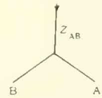


FIG. 21

ance. This impedance may be represented as Z_{AB}, where the first subscript indicates the load point and the second subscript indicates the point to which the drop is considered. If this notation is employed it becomes necessary to distinguish between the two conditions:—1—where A and B are different points; and 2—where they are the same point.

The latter case is indicated by the term "self impedance", which is the actual impedance of the network in the usual meaning of the word. The other case is indicated by the term "mutual impedance". A very important theorem* connecting mutual impedances may be stated very simply as follows:—

$$Z_{AB} = Z_{BA}$$

The validity of this theorem can be shown in the case of a simple network. Take the case of a single mesh as shown in the Fig. 20. Consider first a load of unit current at the point B. The current flowing in the branch Z_1 is,— $\dfrac{Z_2}{Z_1 + Z_2 + Z_3}$ and the drop to the point A, Z_{BA} is evidently,— $\dfrac{Z_1\ Z_2}{Z_1 + Z_2 + Z_3}$

Next consider a load of unit current at the point A, the current in the branch Z_2 is $\dfrac{Z_1}{Z_1 + Z_2 + Z_3}$ and the drop from the source to the point B, Z_{AB} is

*The general proof for this theorem is given in this issue by Mr. Fortescue, to whom the writer is indebted for its use.

$\frac{Z_1 Z_2}{Z_1 + Z_2 + Z_3}$. Hence for this case Z_{AB} is equal to Z_{BA}.

It is possible to obtain a clear picture of the relations existing in this particular case by replacing the delta group of impedances by an equivalent star group as shown in Fig. 21. The mutual impedances in this case are obviously the same, and represent the impedance Z_{AB} common to both paths.

The fact that $Z_{AB} = Z_{BA}$ offers a convenient method for checking the calculation for division of currents. Take the case shown in Fig. 17. The division of currents for the loads at the points *1*, *2* and *3* is easily obtained, then the self and mutual impedances are obtained which may be tabulated in columns for each load point.

$Z_{\cdot 1}$	$Z_{2\text{-}1}$	$Z_{3\text{-}1}$
$Z_{1\text{-}2}$	$Z_{2\text{-}2}$	$Z_{3\text{-}2}$
$Z_{1\text{-}3}$	$Z_{2\ 3}$	$Z_{3\text{-}3}$

The impedances $Z_{1\ 2}$ and $Z_{1\ 3}$ are obtained from a different set of calculations than $Z_{2\ 1}$ and $Z_{2\ 3}$ or $Z_{3\ 1}$ and $Z_{3\ 2}$,hence these checks afford a very good indication as to the accuracy of the calculation.

REGULATION

When the self and mutual impedances have been obtained it becomes a very easy matter to determine the regulation for any particular current loading. The voltage drop D_1 to any point, say the point *1*, is evidently,—

$$D_1 = Z_{1\text{-}1} I_1 + Z_{1\text{-}2} I_2 + Z_{1\text{-}3} I_3$$

Similarly the drop to the point *2* is,—

$$D_2 = Z_{2\text{-}1} I_1 + Z_{\cdot 2} I_2 + Z_{2\text{-}3} I_3$$

When I_1 is the current drawn from the point *1* and I_2 is the current drawn from the point *2*. In the above expressions, the impedances, and the currents are ccmplex quantities, and therefore the phase relations of the currents must either be known or assumed.

TRANSMISSION EFFICIENCY

By extending the above method, the transmission efficiency may be calculated. The total power input to the network is obtained from the sum of the load currents and the voltage of the source. The total power output is the sum of the power delivered to each of the different loads whose voltage and current are both known. The total loss in the network can be calculated from the following expression:

$$Z_{1\text{-}1} I_1 \dot{I}_1 + Z_{2\text{-}2} I_2 I_2 + Z_{3\text{-}3} I_3 \dot{I}_3 \ldots\ldots \text{plus}$$
$$Z_{1\text{-}2} (I_1 \dot{I}_2 + \dot{I}_1 I_2) + Z_{1\text{-}3} (I_1 \dot{I}_3 + \dot{I}_1 I_3) = Z_{2\text{-}3} (I_2 \dot{I}_3 + \dot{I}_2 I_3)$$

In the above expression $\dot{I}$ represents the conjugate of I.

When direct-current networks only are considered, the expressions for impedances and currents are no longer complex quantities and the equations given above for voltage regulation and power loss in the network are much simplified.

EQUIVALENT LOADING

On certain distribution systems, such as trolley systems, the load may be located at any point between two substations or branch points in the network, and it becomes desirable to replace the actual loading by an equivalent loading in which all loads are located at branch points. It has been found that if the actual current loads be divided in inverse proportion to the impedance from the load point to the adjacent branch points, that the same voltage drops and division of current are obtained in all parts of the network except in the branch in which the load is taken, as would be obtained with the actual loading. The equivalent loading is used to obtain the division of current and voltage drops to branch points, and with these obtained, the voltage drop to the load is easily secured and the equation is as follows:—

$$m D_1 + (1-m) D_2 + m\ (1-m)\ Z_c I_x$$

In the above equation, D_1 is the voltage drop to the branch point *1*, and D_2 is the voltage drop to the branch point *2*; Z_c is the impedance on the branch connecting points *1* and *2*; m is the ratio of the impedance between the load point and the branch point *2*, to the impedance Z_c; I_x represents the load current in the branch Z_c. The method of equivalent loading makes it unnecessary to solve the network except for branch points.

POSITIVE AND NEGATIVE LOADING

If the network is supplied by two sources of power, and the amount of power supplied by one source is known, it may be represented by a negative load. The problem under this condition is no more complicated than with one source of power.

By extending these methods, it is possible to eliminate a branch of the network under some particular load condition, even though it is carrying current. Referring to Fig. 17, the impedance Z_2 connected between the points *2* and *2'* may be eliminated by placing a positive load of I_x amperes at the point *2'*, and a negative load of I_x amperes at the point *2*, as shown in Fig. 19. The use of the positive and negative loads satisfies Kirschoff's first law, and to satisfy the second law, the voltage drop between *2* and *2'* must be equal to $Z_2 I_x$. The value of I_x is determined by the above voltage condition, and the complete solution of the network for this condition of load can now be obtained.

This method is of particular advantage when a complicated network has been solved, and it becomes necessary to change the impedance of a certain branch of the network, e.i.; to increase the capacity of a transformer or feeder. The calculation for the network with a new value of impedance in the branch is complicated only to the extent of considering one or two additional loads.

In this article, no attempt at completeness has been considered, but the intention has been to describe a few methods which would be of the greatest assistance in solving the usual network problems. It should be pointed out, however, that in the networks which have been considered, it has been assumed that no branches were mutually interlinked; this rather unusual type of network deserves separate treatment.

Development of Analytical Solutions

Charles Fortescue

A number of years ago the writer had to take up, in connection with the Norfolk & Western Railway electrification, the problem of solving single-phase railway networks. As a result of practical work on railway networks, the theorems and methods referred to in the latter part of the article by Mr. Evans, in which he has presented their practical application, were deduced. The principles on which these methods are based have been known to physicists for some time, but their application to practical problems has not been generally appreciated. These methods have since been used in the calculation of many other railway and central station networks. Mr. Evans has stated these theorems without comment, but it is believed by the author that the derivation and a proof as follows would be of interest to those who may wish to make use of them. One of the principal ideas presented in this article is the separation of the networks into invariable and variable portions, the latter constituting the supply and load circuits. Thus the constants derived for the invariable portion of the network may be tabulated and used whenever a problem comes up for solution. Corrections for changes in the network can be readily worked out and the tables of constants kept.

There are portions of most networks which are not subject to variation; thus, for example, a high-voltage transmission system supplying power through step-down transformers to a secondary distribution system will have the impedance of the transmission lines, of the transforming apparatus and the impedance of the secondary distribution system, in general invariable or else subject to arbitrary variation. On the other hand the loads drawn from such a system at various points will be subject to variations which are not controlled. Again the secondary transmission of the system described above may consist of the overhead trolley and tracks of a railway; in this case the load will not only be subject to variation in value but also in position.

In the case of a single network problem it is not important to take account of the variable and invariable portions of the network, but when the complete network is the subject of extensive investigation, the importance of separating the portions subject to variation from those that remain constant is obvious. In the case of a single-phase railway network, the complete solution of the network for unit current at one secondary branch point may be used as a basis for deducing the solutions for all the other branch points by simple transformations. With the solution for all the branch points given, that for a load at any point on the system is a matter simply of superposition of solutions, with the help of a certain theorem of resolution of loads to equivalent loads at branch points. The theorem of superposed solutions may be stated as follows:—

> If a number of currents are drawn from a network at various points, the resulting distribution of currents in the invariable portions of the network will be the same as that obtained by considering each load separately and superposing the separate solutions, the currents in the various portions of the network being combined vectorially.

When the loads are located at branch points and there is one supply point, this theorem follows directly from Kirchhoff's law of e.m.f. taken round a closed circuit. Since the sum of these e.m.f.'s in each circuit is zero for each load taken separately, it must also be zero for the superposed solutions and therefore the superposed solution satisfies Kirchhoff's law and is the solution for the combined loads.

In applying this to loads that do not occur at branch points it is necessary to introduce the theorem of resolution of a current into components at the adjacent branch points. This theorem may be stated as follows:—

> A current due to a load intermediate between two branch points may be resolved into two components flowing from the adjacent branch points of such values that they will produce no difference of potential between these two points. The actual load current may therefore be considered as transferred in like proportion to these branch points; the distribution resulting therefrom together with the components in the conductor between the branch points and load combined being the true solution. Where there are a number of feeders connecting two adjacent branch points each carrying one or more loads, the mutual impedances of the currents must be taken into account in determining the difference of potential between the branch points, but each load may be resolved separately and independent of the others.

This theorem also follows directly from Kirchhoff's law of e.m.f. round a closed circuit, for this law is satisfied for all the closed circuits intercepted between any given pair of branch points and it introduces no difference of potential between any pair of branch points and will therefore introduce no e.m.f. in any mesh of the invariable part of the system which contains the branch points. Therefore, the superposed solution for the combined resolved loads at branch points, together with the currents between the actual load points and the branch points due to resolving the load current in the manner specified, gives a solution satisfying Kirchoff's laws and is the true solution.

METHOD OF PROGRESSIVE APPROXIMATIONS

It is frequently the case that a rigid solution of the system is not desired, the loads themselves being subject to such large fluctuation and variation in power-factor that extreme nicety in determining their probable values and power-factor is not possible. What is generally desired is a means of obtaining, with reasonable accuracy, the distribution of loads among the transformers and other apparatus in the system. The loads in general may therefore be considered to have an average power-factor through the whole system, or they may be classified into two or more classes having different power-factors and the resulting solutions superimposed. If a greater degree of accuracy is desired, the e.m.f.'s at each load point may be calculated from the distribution obtained as above and the current at each load point then adjusted to its proper phase relation. The calculations are then repeated. This cycle of operations may be repeated as many times as necessary to obtain the degree of accuracy desired.

LOAD POINTS TO REPRESENT CAPACITY ADMITTANCE

The points at which a load may be supplied need not, from a theoretical point of view, be limited to the secondary distribution. This fact affords a very convenient way of taking into account such factors as distributed capacity. Applying the theorem of component load at branch points to the capacity currents, as far as the network is concerned the only factor of consequence is the amount of the component current flowing from each branch point and the manner in which it distributes itself throughout the circuit. We may therefore consider all capacity current between two branch points to be equally divided between them and calculate the distribution in the networks resulting therefrom. Where it becomes necessary to consider such factors, the current distribution for unit loads at the high-tension branch points must also be worked out.

NEGATIVE LOAD POINTS

Where a system is fed from two or more separate sources of power, one of these may be taken as the principal one and the others may be considered as negative load points, the resulting solutions being superposed in the same manner as for positive load points. If the negative load point lies between two branch points, it may be treated in a similar manner to that of a positive load point lying between two branch points. The method of successive approximation may be applied in all these cases. In the case of additional supply points, the number is usually few and, therefore the labor in obtaining a satisfactory solution by successive approximation is small.

SELF-IMPEDANCE AND MUTUAL IMPEDANCE—RECIPROCAL RELATIONS IN A NETWORK

If a unit current load be taken from a network at a given point, the drop in the network between the supply point and the load point is the impedance of the network to a load at that point. If the load points are designated by the letters *A*, *B*, *C*, *D*, etc., the self-impedances are designated usually by Z_a, Z_b, Z_c, etc. If unit current is taken from *A*, the e.m.f. between the supply point and *B* is the mutual impedance between *A* and *B*, designated by Z_{AB}. Conversely if unit current is drawn from *B*, the e.m.f. between the supply point and *A* is the mutual impedance between *B* and *A* and is designated Z_{BA}. In all linear systems $Z_{AB} = Z_{BA}$. This is the reciprocal theorem for mutual impedances in a network.

*The proof of this theorem is as follows:—the mean magnetic energy in a network composed solely of inductive apparatus is given as,—

$$T = \sum \Big(\frac{1}{2} L_1 i_1^2 + \frac{1}{2} L_2 i_2^2 + M_{12} i_1 i_2 + M_{13} i_1 i_3 + \ldots\ldots \Big) \ldots\ldots\ldots\ldots\ldots \quad (1)$$

and the energy dissipated is given by,—

$$W = \sum \Big\{ \int R_1 i_1 dq_1 + R_2 i_2 dq_2 + R_3 i_3 dq_3 + \Big\} . \quad (2)$$

Where i_1, i_2, i_3, etc. are the component currents in the network and q_2, q_2, q_3 are the quantities of electricity that flow past a given point in the network in a given time. If the load currents at *A* and *B* are i_A and i_B, we may express i_1, i_2 and i_3 in terms of these two currents. Thus:—

Another reciprocal relation that occurs in networks may be stated as follows.

> If in any network, an e.m.f. set up between two points *A* and *B* causes current *i* to flow between two other points *C* and *D* when connected together, the same e.m.f., if applied between *C* and *D*, will cause the same current to flow between *A* and *B* if they are connected together.

COMPLETE SOLUTION OF NETWORK FOR ALL LOADS

After having obtained the values of Z_a, Z_b, Z_c, etc., and Z_{ab}, Z_{ac}, Z_{bc}, etc. of the network for the load points

$$\left.\begin{aligned} i_1 &= h_1 i_A + k_1 i_B \\ i_2 &= h_2 i_A + k_2 i_B \\ i_3 &= h_3 i_A + k_3 i_B \end{aligned}\right\} \ldots\ldots\ldots \quad (3)$$

Where h_1 k_1 h_2 k_2 etc., are constants depending solely upon the position of *A* and *B* in the network. The same relation will hold between dq_1, dq_2 etc., and dq_A, dq_B. Substituting these expressions in (1) and (2) gives *T* and *W* in terms of i_A,—

$$\begin{aligned} T = \sum \Big(& \frac{1}{2} L_1 h_1^2 + L_2 h_2^2 + L_3 h_3^2 + \ldots\ldots \Big) i_A^2 \\ & + \frac{1}{2} \Big(L_1 k_1^2 + L_2 k_2^2 + L_3 k_3^2 + \ldots\ldots \Big) i_B^2 \\ & + (M_{12} h_1 h_2 + M_{13} h_1 h_3 + \ldots\ldots\ldots\ldots\ldots\ldots) i_A^2 \\ & + (M_{12} k_1 k_2 + M_{13} k_1 k_3 + \ldots\ldots\ldots\ldots\ldots\ldots) i_B^2 \\ & + (L_1 h_1 k_1 + L_2 h_2 k_2 + L_3 h_3 k_3 + \ldots.) \\ & + (M_{12} (h_1 k_2 + h_2 k_1) - M_{13} (h_1 k_3 + h_3 k_1) + ..) i_A i_B \end{aligned}$$

$$\begin{aligned} W = \sum \Big\{ \int & (R_1 h_1^2 + R_2 h_2^2 + R_3 h_3^2 + \ldots\ldots) i_A dq_A \\ & + (R_1 k_1^2 + R_2 k_2^2 + R_3 k_3^2 + \ldots\ldots) i_B dq_B \\ & + (R_1 h_1 k_1 + R_2 h_2 k_2 + R_3 h_3 k_3 + \ldots.) i_A dq_B \\ & + (R_1 h_1 k_1 + R_2 h_2 k_2 + R_3 h_3 k_3 + \ldots) i_B dq_a \Big\} \ldots (5) \end{aligned}$$

The e.m.f. set up in the network in the composite circuit including *A* will be:—

$$\frac{d}{dt}\frac{dT}{di_A} + \frac{dW}{dq_A} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

and in the circuit including *B* it will be:—

$$\frac{d}{dt}\frac{dT}{di_B} + \frac{dW}{dq_B} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

The portions of (6) and (7) involving *T* become, on substituting its value from (4):—

$$\begin{aligned} \frac{d}{dt}\frac{dT}{di_A} = \frac{d}{dt} \sum \Big[& (L_1 h_1 + L_2 h_2 + L_3 h_3^2 + \ldots\ldots) i_A \\ & + 2 (M_{12} h_1 h_2 + M_{13} h_1 h_3 + \ldots) i_A \\ & + \{ L_1 h_1 k_1 + L_2 h_2 k_2 + L_3 h_3 k_3 + \ldots..) \\ & + M_{12} (h_1 k_2 + h_2 k_1) + M_{13} (h_1 k_3 + h_3 k_1) + .. \} i_B \Big] \ldots (8) \end{aligned}$$

$$\begin{aligned} \frac{d}{dt}\frac{dT}{di_A} = \frac{d}{dt} \sum \Big[& (L_1 k_1 + L_2 k_2 + L_3 k_3 + \ldots\ldots) i_B \\ & + 2 (M_{12} k_1 k_2 + M_{13} k_1 k_3 + \ldots\ldots\ldots\ldots) i_B \\ & + \{ L_1 h_1 k_1 + L_2 h_2 k_2 + L_3 h_3 k_3 + \ldots\ldots\ldots \\ & + M_{12} (h_1 k_2 + h_2 k_2) + M_{13} (h_1 k_3 + h_3 k_1) \ldots \} i_A \Big] .. (9) \end{aligned}$$

The coefficients of i_a in (8) is the quadrature e.m.f. between the supply point and *A* due to unit current at *B*, and the coefficient of i_b in (9) is the quadrature e.m.f. between the supply point and *B* due to unit rate of increase of current at *A*. It will be seen that the two are equal. Equations (8) and (9) therefore show that for unit alternating current i_A, the quadrature e.m.f. at *B* equals the quadrature e.m.f. at *A* for unit current i_B or,—

$$M_{AB} = M_{BA} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (10)$$

Similarly we have:—

$$\begin{aligned} \frac{\partial W}{\partial q_A} = \sum \Big\{ & (R_1 h_1^2 + R_2 h_2^2 + R_3 h_3^2) i_A \\ & + R_1 h_1 k_1 + R_2 h_2 k_2 + R_3 h_3 k_3 \ldots\ldots) i_B \Big\} .. (11) \end{aligned}$$

$$\begin{aligned} \frac{\partial W}{\partial q_A} = \sum \Big\{ & (R_1 k_1^2 + R_2 k_2^2 + R_3 k_3^2) i_B \\ & + R_1 h_1 k_1 + R_2 h_2 k_2 + R_3 h_3 k_3 + \ldots) i_A \Big\} .. (12) \end{aligned}$$

The coefficient of i_b in (11) and i_a in (12) are equal. Therefore equations (11) and (12) show that for unit alternating current i_A, the in-phase e.m.f. at *B* equals the in-phase e.m.f. *A* for unit current i_B. Or,—

$$Z_{AB} = Z_{BA}$$

A, B and C and having given the load impedance Z_1, Z_2, Z_3 etc., the equation of the system with an impressed e.m.f. E is:—

$$
\begin{aligned}
\dot{E} &= (Z_a + Z_1)\,\dot{I}_a + Z_{ab}\,\dot{I}_b + Z_{ac}\,\dot{I}_c + \ldots. \\
&= Z_{ab}\,\dot{I}_a + (Z_b + Z_2)\,\dot{I}_b + Z_{bc}\,\dot{I}_c + \ldots. \\
&= Z_{ac}\,\dot{I}_a + Z_{bc}\,\dot{I}_b + (Z_c + Z_3)\,\dot{I}_c + \ldots \quad (13)
\end{aligned}
$$

The solution can be obtained in the usual determinant form. After values of the currents have been determined, the e.m.f.'s at each point can be calculated in the usual manner.

CHANGE IN SUPPLY POINT

The point at which the power is supplied to a network may be changed to another point by the simple expedient of considering a negative load of the same value as the total load at the supply point to be taken off at the other point. This will reduce the load at the former supply point to zero and give the proper current distribution throughout the net work for the new point.

NETWORK WITH MORE THAN ONE SUPPLY POINT

It was pointed out in a previous paragraph that additional supply points may be represented by negative load points, and that a satisfactory solution may be reached by the method of successive approximation. It will appear in arriving at the solution in this manner that the loads which the various supply stations take can, to a large extent, be arbitrarily determined. The reason of this will appear below. Let the additional supply points be U, V, W having impedances, referred to the initial supply point O, of Z_u Z_v Z_w and having mutual impedances with the various load points designated in the usual manner. Let us suppose the current taken off at these points to be $-\dot{I}_u - \dot{I}_v - \dot{I}_w$ and let the impressed e.m.f.'s at these points be E_u, E_v, E_w, no limitation being placed on the value of the currents or e.m.f.'s. Instead of equation (13) we now have:

$$
\begin{aligned}
E &= -Z_{au}\,I_u - Z_{av}\,I_v - Z_{aw}\,I_w + (Z_a + Z_1)\,I_a + Z_{ab}\,I_b + Z_{ac}\,I_c + \ldots \\
&= -Z_{bu}\,I_u - Z_{bv}\,I_v - Z_{bw}\,I_w + Z_{ab}\,I_a + (Z_b + Z_2)\,I_b + Z_{bc}\,I_c + \ldots \\
&= -Z_{cu}\,I_u - Z_{cv}\,I_v - Z_{cw}\,I_w + Z_{ac}\,I_a + Z_{bc}\,I_b + (Z_c + Z_3)\,I_c + \\
&= E_u - Z_u\,I_u - Z_{uv}\,I_v - Z_{uw}\,I_w + Z_{au}\,I_a + Z_{bu}\,I_b + Z_{cu}\,I_c \quad \ldots\ldots \\
&= E_v - Z_{uv}\,I_u - Z_v\,I_v - Z_{vw}\,I_w + Z_{av}\,I_a + Z_{bv}\,I_b + Z_{cv}\,I_c + \ldots\ldots \\
&= E_w - Z_{uw}\,I_u - Z_{vw}\,I_v - Z_w\,I_w + Z_{aw}\,I_a + Z_{bw}\,I_b + Z_{cw}\,I_c + . \quad (14)
\end{aligned}
$$

There are three additional equations to determine six new quantities namely I_u I_v I_w E_u E_v E_w. It will therefore be evident that three of these quantities may be determined arbitrarily if there are no other factors limiting their values.

FREEDOM AND CONSTRAINT

A quantity is said to have n degrees of freedom if n quantities are required to completely specify it. Thus a plain vector has two degrees of freedom since it is completely specified by its length and angular position. Any relation which furnishes a means for specifying an undetermined quantity is called a constraint. Thus in the network with one supply point which has been treated in the preceeding paragraphs, the values of the e.m.f.s and currents are subjected to constraints by virtue of their relation to one another through the network.

The system represented by (14) has six degrees of freedom, since we can vary any three of the six vector quantities E_u, E_v, E_w, I_u, I_v, I_w arbitrarily. We may impose six degrees of constraint by expressing three independent relations between any three of these quantities and one or all of the remaining quantities entering into the system. Thus for example if we make,—

$$\dot{E}_u = \dot{E}_v = \dot{E}_w = \dot{E} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (15)$$

The system is completely specified when these relations are substituted in (14). On the other hand if we simply specify,—

$$E_u = E_v = E_w = E \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (16)$$

only three constraints are imposed for the reason that the vectors E_u E_v E_w are not completely specified by (16), the phase angles of these vectors being still left undetermined. Similarly constraints may be imposed on the currents instead of the e.m.f.'s though it is more usual to fix the value of the e.m.f.

A common constraint imposed is to keep the voltage at all supply points the same and operate at the same power-factor at these points. These constraints are expressed as follows,—

$$
\left.
\begin{aligned}
I_u &= Y_u\,E_u\,\varepsilon^{j\theta} \\
I_v &= Y_v\,E_v\,\varepsilon^{j\theta} \\
I_w &= Y_w\,E_w\,\varepsilon^{j\theta}
\end{aligned}
\right\} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (17)
$$

$$I_a + I_b + I_c - I_u - I_v - I_w = YE\varepsilon^{j\theta} \ldots\ldots (18)$$

M_u Y_v Y_w and Y are real quantities. Equation (17) specifies four vector quantities but leaves five real quantities, Y_u Y_v Y_w Y and θ undetermined. It removes, therefore, three degrees of freedom from the system. Equation (16) constitutes a constraint of three degrees, therefore (14) with (16) and (18) completely specify the system. The constraints may be specified in the form of relative division of load between power houses with equality of voltage; these specifications alone constitute an additional constraint of six degrees and therefore the power-factors would be determined by the relations in the network.

The above relations are possible when the supply stations are completely independent, but quite frequently the supply stations are fed from an external source, by means of motor-generators or other transforming apparatus. These factors will introduce constraints into the system independent of those imposed by the network, which will depend in part upon the character of the transforming apparatus. The voltage and current relations at the supply points will, in these cases, be less subject to arbitrary control, unless provision be made by means of regulators or phase shifting devices to regain the freedom lost through the external connections.

Equations (13) and (14) with the constraints imposed, may be solved by determinants in the usual way, but for most work it will be found less troublesome to use the method of progressive approximation, as outlined previously, or the values of load current may be determined arbitrarily and I_u, I_v and I_w obtained by substituting them in the last three equations of (14), making use of the desired constraints as indicated for the general solution.

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

AUGUST 1919

Maintenance of Magnet Valves

With the proper attention to the upper and lower valve stems of magnetic valves used with electropneumatically-operated switches, the valve seats should last for several years. There are cases, of course, when the valve seats become so badly worn that an early renewal is required.

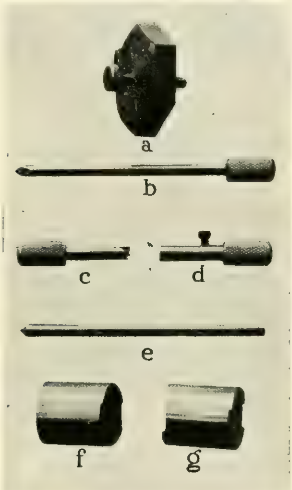


FIG. 1—TOOLS

CAUSES OF VALVE SEAT WEAR:

The bushings which contain the valve seats are made from brass rod bought according to prescribed specifications, so that an even grade of material can be obtained. Although other materials, such as steel, etc., would give a greater life as far as wear of valve seat is concerned, brass combines both qualities of wear and ease of obtaining a satisfactory ground seat with a minimum of work. This can readily be understood by those who have ground in compressor valve seats. Since brass is, however, a relatively soft material, the continued pounding of the valve stem would soon mash the seat out of shape if the material in the stem was too hard. To prevent this the stem is made of bronze, of a composition only slightly harder than the valve seat. It has been found that the combination of brass seat and bronze stem gives the best results for both "grinding in" and wear.

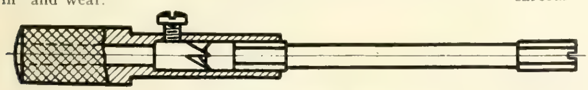


FIG. 2—USE OF UPPER VALVE STEM SCRAPER

When it becomes necessary to make extensive repairs to valve seats where cutting and grinding are necessary, the valve magnet should be removed to a bench. Before taking definite steps with the repairing of valves, a complete set of tools should be obtained. A number of the tools can be made; but to obtain the best results, tools similar to those now on the market should be used.

REPAIRING OF SLIGHTLY WORN BUSHINGS AND STEMS:

Valve bushings which have become leaky and which cannot be ground in, can easily be repaired by first resetting the seats with the set shown in Fig. 1 (e) and then cutting them to shape with the cutter in Fig. 1 (b). The upper valve stem should be trimmed with the tool in Fig. 1 (d) and the lower valve stem with the tool in Fig. 1 (c). Figs. 2 and 3 show the use of these tools.

The uses of the valve set and shapes are shown in Figs. 4 and 5. When setting and shaping the lower valve seat it is necessary to have a guide for the tools. This is easily obtained by drilling a hole in a spare lower valve nut, slightly larger than the diameter of the tools. Figs. 4 and 5 show this hole in the nut.

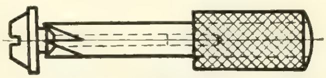


FIG. 3—USE OF LOWER VALVE STEM SCRAPER

REPLACING BADLY WORN VALVE BUSHINGS:

When replacing a worn bushing first dismantle the magnet by removing the top, armature, core and coil. Drive out the old bushing from the bottom valve side, and drive in the new bushing from top. New bushings are supplied with a small drilled hole for the ports which must be drilled out to the same

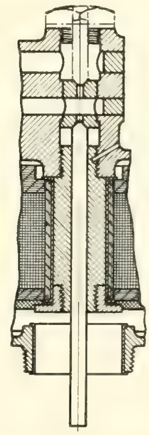


FIG. 5—USE OF VALVE SEAT SCRAPER

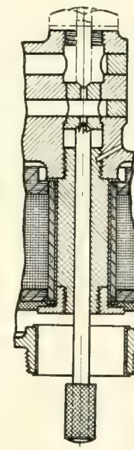


FIG. 8
USE OF VALVE SEAT SET

size as the old bushing after the new bushing is in place. Be careful not to drill all the way through the bushing, as there is usually a difference in the exhaust and inlet ports. After the ports have been drilled, the valve seats should be cut with the tool shown in Fig. 1 (b). There are some valve magnets which have the bushing driven in from the bottom. When removing such a bushing, it must be driven out from the top with a special hardened drift.

GRINDING OF VALVE SEATS:

After the valve seats have been reamed, whether for slightly worn or new bushings, it is necessary to grind the valve stem into the seat for an air tight fit. The most satisfactory results are obtained as shown in Fig. 10. With this arrangement both valve seats can be ground from above by turning the valve magnet upside down. It is also possible to test the condition of the valve seat with the air on. When using this device, the air passage to the cylinder should be plugged if the cylinder has been removed. In grinding the valve, the seat is covered with a thin mixture of pumice stone and oil. The valve stem is put in place as shown in Fig. 6 and spun back and forth by some such method as is shown in Fig. 11.

SETTING OF VALVE STEMS:

The arrangement of the upper and lower valve stems in connection with the valve seat bushing is shown in Fig. 7. The

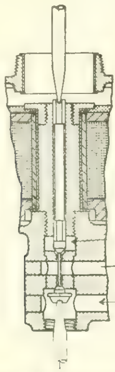


FIG. 6—VALVE STEMS IN PLACE FOR GRINDING

length of the lower valve stem should be such that the travel of the upper and the lower stems to seat the upper valve stem

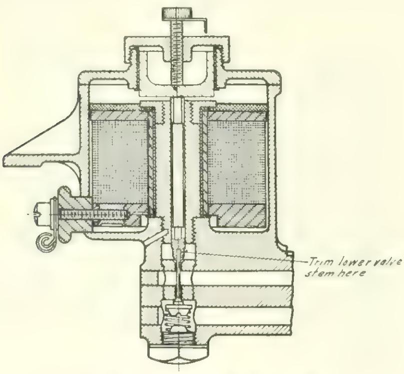


FIG. 7—USE OF TRAVEL GAUGE

is $\frac{1}{32}$ inch. This travel is adjusted by means of the special cap shown in Fig. 7. The cap which forms part of the set of tools

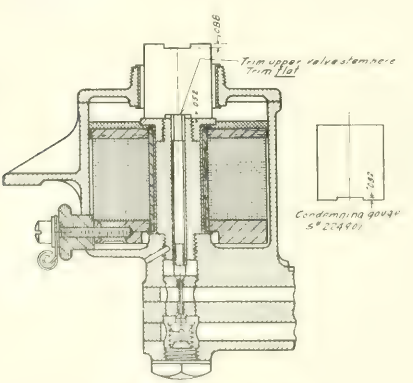


FIG. 8—USE OF CAP GAUGE

is shown in Fig. 1 (e). It has a thumb screw terminating at the top end with a pointer. In using this gauge the regular cap is removed and the gauge screwed on in its place. The thumb screw which has previously been turned up, is then screwed down until the switch closes. Back off the thumb screw until the lower valve stops blowing. The pointer should have made one complete revolution, showing that valve stems had traveled $\frac{1}{32}$ inch as the thumb screw has 32 threads to the inch.

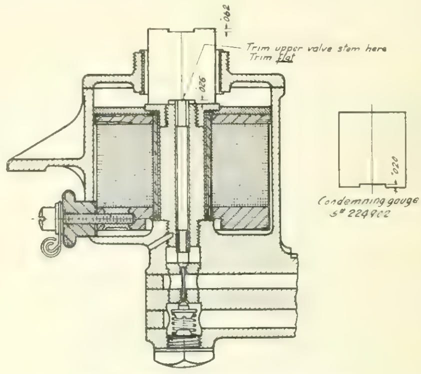


FIG. 9—USE OF CONDEMNING GAUGE

When adjusting the upper valve stem, use a gauge such as shown in Fig. 1 (g). When using this gauge, remove the cap and armature, and place the gauge with the slot marked 0.008 in. down, over the valve stem as shown in Fig. 8. If the lower valve blows or the switch closes, the stem is too long. File off the top of the stem with a smooth file. In order to file the

FIG. 10—METHOD OF GRINDING VALVE SEAT

APPARATUS FOR SPINNING THE VALVE STEM BACK AND FORTH

top perfectly flat, it would be well to use a jig similar the one shown in Fig. 12. Be careful not to cut too much off at one time before trying the gauge, as a stem too short must be peaned out or thrown away. After the stem has been shortened sufficiently so that the lower valve does not blow, and the switch does not close with the 0.088 in. gauge, the 0.052 in. gauge should be used (this is the slot on the other end of the gauge shown in Fig. 1 (g). The switch should close and the top

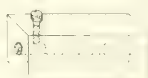


FIG. 12—JIG

valve should not blow. If the top valve blows the top valve stem is too short. The stem can be lengthened by peaning with a hammer. After any change in the valve stem due to filing or peaning, the gauges should be used. The gauge shown in Fig. 1 (f) is used when condemning a valve stem. If the upper valve blows and the switch does not close, the upper valve stem is too short and should either be peaned out or a new stem inserted.

In place of the gauge with 0.088 in. and 0.052 in. slots, use one with 0.062 in. and 0.026 in. slots in the same manner as explained above. The condemning gauge is fitted with a 0.020 in. slot.

H. R. MEYER

THE JOURNAL QUESTION BOX

OUR subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. The topics should be of general interest, information involving the specific design of individual pieces of apparatus is not supplied. Care should be used to include all data necessary for an intelligent answer.

A PERSONAL reply is mailed to each questioner enclosing a stamped, self addressed envelope as soon as the necessary information can be obtained. Anonymous questions cannot be considered. As each question is answered by an expert on the subject involved, and checked by at least two others, a reasonable length of time should be allowed before expecting an answer.

1773—TRANSFORMER BANK—Would it be advisable to install a five kw transformer in a bank of two 30 kw, one of a set of three having burned out, and was cut out, then the remaining two carried the load fairly well? A fifteen kw being available, would it be good practice to install it together with the two 30 kw? R.O, (GEORGIA)

This is not advisable, as the small transformer would probably burn out. If the two 30 k.v.a. transformers in open delta have sufficient output for the load, this arrangement is satisfactory. If not, another open delta bank may be

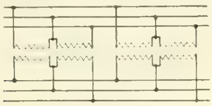


FIG. 1773(a)

connected in parrallel, using the same or a different size of transformers, provided the impedance of the two banks is not too far different. The point of the V in both banks should be connected to the same line wire, as shown in Fig. (a). J.B.G.

1774—INDUCTION MOTOR WINDING—Please send a drawing changing a two-phase motor to three-phase, making a Y delta as shown in Fig. (a) so as to avoid splitting groups. W.H.C. (CAL.)

To reconnect a two-phase motor for three-phase operation, without breaking up the groups of coils, take for example, a six-pole, two-phase motor which will have twelve groups of coils and reconnect it for four poles, three-phase, which will also require twelve groups of coils. The same change could be made for any multiple of six and four poles, as for example a twelve-pole, two-phase motor could be reconnected as an eight-pole, three-phase motor without breaking up the coil groups. Both the primary and the secondary

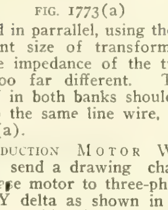


FIG. 1774(a)

windings of the motor would have to be reconnected in case the motor was of the phase-wound rotor type, and the change could not be made if either winding was a wave winding. Such a change would, however, change the chording of the winding and corrections would have to be made for this, as described in the article on "Reconnecting Induction Motors" by Mr. A. M. Dudley, in the JOURNAL for Feb. 1916 G.F.S.

1775—MAGNETIC CENTER OF GENERATOR—I would like to know the proper method of determining the magnetic center, that is the point which the rotor will asume if allowed to find its own center, of a 1500 kw, 3 phase, 1800 r.p.m. steam turbine driven alternating-current generator. Can it be found by measuring the iron of the rotor and stator and if so how much could the center line of the rotor iron be out from the center line of the stator iron, when the stator iron measures 8 ft. ¾ inches and the rotor iron 8 ft. outside to outside measurements. If the generator were run as a synchronous motor and allowed to find its center would that be correct for the generator under full load? E.E.S. (OHIO)

In assembling a turboalternator, the vertical center line of the stator iron should be lined up with the center line of the active iron of the rotor and the rotor will then be in its magnetic center, provided the flux density is equal on both ends of the machine. Unequal flux densities on either side of the center line may be caused by the iron being built up tighter on one side than the other, and result in a thrust which will throw the centers out of line when running, but this movement is so slight that it can be taken care of in the play of the bearing. If both bearings are at the same elevation, the rotor will find its true magnetic center when the machine is run as a synchronous motor, and will not change between no load and full load. Usually, however, the two outboard bearings of a turbine driven unit are slightly elevated in order to bring the two faces of the coupling parallel to each other, and in this event, if the generator were run as a synchronous motor, the rotor would drift toward the inboard bearing and away from its magnetic center. S.L.H.

1776—BOOSTER CONVERTER—Consider a 9000 volt line supplying a delta primary transformer and booster type rotary converter rated at 2000 kw, 7400 amperes, 270 volts, direct-current and 240 to 300 volts direct-current with aid of the booster. Suppose this converter is delivering 7400 amperes at 270 volts with the booster idle; that is, on neutral. Disregarding the efficiency of the equipment, the current per phase of the line would be 2 000 000 ÷ (9000 × 1.73) or 128.5 amperes approximately. Now suppose this converter is used to deliver 7400 amperes at 300 volts, the booster operating at full boost. By a similar calculation, the current per phase of the line would be 2 220 000 (power delivered) ÷ (9000 × 1.73) or 142.6 amperes approximately. In this case the current in the line is 14.1 amperes more than in the other, or 219.5 kw—the power necessary for the booster when operating at full boost. If the foregoing is correct, please explain how and what parts of the equipment this extra current traverses, and what heating effects it will have. C.D.B. (ILL.)

When the booster is acting to raise the direct-current voltage, it is operating as a generator (its generated voltage being in the same direction as the current in its windings) and the main converter operates as a synchronous motor to drive it. Assuming a constant direct-current, as you have, the direct-current voltage is increased (amount of boost). Therefore, since the alternating-current voltage applied to the collector rings is unchanged, an additional current is drawn from the alternating-current side, as you have deduced, to supply the increased direct-current output. This additional current traverses the transformer, booster and main converter windings, without being commutated to the direct-current side, just in the same way, as if the converter were operated as a synchronous motor (so far as this additional current is concerned.) It has the effect of increasing the armature heating of the converter. The average heating of the entire armature winding, expressed as a percentage of the armature heating of the same machine when operated as a direct-current generator at the same output, at any amount of buck or boost, may be expressed as follows:—

$$\left\{ \frac{4\,(1+B)}{e\,\phi\,\sin\left(\frac{180}{\phi}\right)} \right\} \times \frac{secant^2\, y}{2} - \frac{16\,(1+B)}{e\,\pi^2} + 1$$

where,

B = amount of buck or boost, in percent.

y = phase angle between line voltage and line current (cos y = P.F.)

ϕ = number of collector rings.

e = efficiency including booster losses.

Then, the increase in armature heating for this particular case (assuming a six-phase machine, unity power-factor and 100 percent efficiency) is approximately eleven percent. M.W.S.

1777—WIRE DRAWING—In some performance specifications I see a clause to the effect that "wire-drawing = 4.7 lb." I suppose that this refers to the loss in steam pressure due to the steam flowing through the inlet ports of the pump. But I am not sure as to just what it means. H.B. (MO.)

The word "wire drawing" is ordinarily used to express a more or less sudden pressure drop in a steam piping system, such as might be caused by an orifice or a valve of restricted area, causing a higher velocity at this point than the normal velocity in the piping. J.T.J.

1778—SHIFTING BRUSHES WITH THE LOAD ON NON-COMMUTATING POLE MACHINES—Why must the brushes of a direct-current machine be shifted with rotation (lead) on a generator and against rotation (lag) on a motor, and why should the commutating

poles of a direct-current generator be leading and of a motor lagging?

E.J. (ILL.)

The reason for the necessity of shifting brushes with the load on non-commutating pole machines is that the current in the armature shifts the flux from the main pole to one side of its normal no-load position and it is necessary to shift the brush to the same extent that the field is shifted in order to keep them in the neutral or best commutating position. The explanation of this shifting of the flux is discussed completely in an article on "Armature Reaction in Direct-Current Machines" by R. H. Taber in the JOURNAL for Jan. '14, p. 65. The reason for having the commutating pole of a direct-current generator of opposite polarity from that of a direct-current motor is that the current in the armature is in the opposite direction in a motor and in a generator having the same brush polarities. The function of a commutating pole is to provide a flux which will reverse the current in the short-circuited coil during commutation. And as these currents are in opposite directions in a motor and in a generator it is obvious that the commutating poles must be of opposite polarity. C.R.R.

1779—HORSE-POWER OF RECONNECTED MOTOR—What would be the horse-power of a 35 hp. three-phase, 440 volt, 1800 r.p.m. induction motor, the proper stator connection of which is one circuit delta, if connected one circuit star, and would it have a tendency to overheat the rotor bars? What would be the horse-power if connected two circuit star?

E.E.S. (OHIO)

If this motor is connected one circuit star it will have a normal voltage rating of 1.73 × 440 volts or 723 volts. If connected two circuit star it will have a normal voltage rating of one-half the above or 362 volts. The horse-power rating of the motor will not be changed by these changes in connection, provided a suitable voltage is applied to the motor. If, however, the motor is run on 440 volts, its operation will be quite unsatisfactory with either of the above connections. The effect of operating a motor at incorrect voltage is given in an article on "The Effect of Voltage or Frequency Variation on Induction Motor Characteristics" by Mr. L. W. Smith, published in the JOURNAL for March '17, p. 105. In general the effect of operating on increased voltage is to increase the core loss, magnetizing current and torque almost with the square of the voltage and to decrease the slip or copper loss almost in proportion with the square of the increase of voltage. The effect of operating on reduced voltage is exactly the opposite of the above, the particular effect being that the copper loss is greatly increased and the torque and speed considerably reduced. C.R.R.

1780—PHASE SPLITTER—I wish to split a single-phase, 110 volt, 25 cycle circuit into a two-phase circuit for running a two-phase motor. The motor is ⅛ hp, 25 cycle two pole, 110 volt squirrel-cage. I wish to use a condenser in series with one phase to displace the currents in the two phases by the necessary 90 degrees angle. Please let me know what capacity condenser it will require to handle the current in one phase at full motor load and show method of arriving at the result. The object of splitting the phase is not for starting only but for running the motor at full load as a regular two-phase motor. Apart from the cost and space taken up by the condenser, is there any objection to this arrangement? J.H.S. (ONTARIO)

It would not be feasible to attempt running a ⅛ hp, 25 cycle, two-phase, 110 volt motor from a single-phase circuit by using a condenser in series with one phase. A condenser for 110 volts, 25 cycles, of sufficient capacity to allow much current to flow would be out of all reason in size. Unless the phase displacement is very close to 90 degrees the loss would be large and cause excessive heating, because it takes very little phase unbalancing in a circuit to increase the losses in the motor greatly. This would not be serious, of course, if the condenser circuit was used for starting only. For the case in question we would suggest using a resistance in series with one of the motor phases, open circuiting this phase after the motor has come up to speed. The resistance may be best determined by experiment. There are so many variables in such a calculation that any simple method of calculation we might give would be of little value. Any calculation of this sort involves a knowledge of the constants (resistance and reactance) of the motor in question as well as the specification for the winding, which is in most cases not available. G.H.G.

1781—INSULATION FOR OUTDOOR WIRES—Is there any difference in the insulation which should be required on 600 volt and 2200 volt wires which are to be installed outdoors, overhead?

M.J.I. (D.C.)

The National Electrical Code requires that that portion of the service wires between the main cutout and switch and the first support from the cutout or switch on the outside of the building must have an approved rubber insulating covering, but from the above mentioned support to the line, except when run in conduit, may have an approved weather proof insulating covering if kept free from awnings, swinging signs, shutters, etc. The rubber insulated wire referred to here must be insulated according to the voltage of the circuit. That is, for 2200 volts it would have a thicker insulation than for a 600 volt circuit. The weatherproof wire is made with one thickness of insulation for all voltages. D.H.

1782—PARALELL OPERATION OF COMPOUND-WOUND COMPENSATED GENERATORS—I have two 250 volt direct-current generators that I wish to run in parallel. One is a 150 kw compound-wound Goodman and the other is a 200 kw Ridgeway with a compensating winding. In wiring up these machines should there be an equalizing connection between the series winding and the armature of the Goodman machine and between the compensating winding and the armature of the Ridgeway machine as is usually the case when both machines are compound wound, or should the compensating winding on the Ridgeway be treated as part of the armature, as is the case with a commutating pole machine, thereby eliminating the equalizer wire? If it is necessary to have an equalizing wire is it necessary to insert resistance in the series field circuit of the Goodman machine so as to adjust the division of load on the two machines? What effect would it have if the above resistance was inserted in the equalizing wire between the two machines in place of the series field circuit?

E.M. (MO.)

Ridgeway generators are sometimes provided with series field windings, in which case the compensating winding has no compounding effect. The problem of paralleling such a machine with another is the same as with an ordinary machine, the equalizer connection being made between the compensating and series field windings. It appears more likely in the present instance that no series winding has been provided, and that the compensating winding is arranged to give voltage compounding. The following statements are on this basis. The first thing to do in adjusting these machines for parallel operation is to make the change in voltage from no load to full load approximately the same with each generator acting alone. A slight degree of adjustment probably can be obtained by shifting the brush rigging of the Ridgway or the Goodman generator; but this adjustment likely will have to be secured by shunting current from the series winding of the Goodman generator if the latter has the greater compounding; or, if the compounding of the Ridgway generator should be reduced, this may be done by increasing the speed regulation of this unit by means of engine governor adjustments. Then, the voltage drops (from equalizer terminal to main bus bar) over the series field circuit of the Goodman machine and the compensating winding of the Ridgway machine, with full load and the generators acting independently, should be made approximately the same. This may require inserting a resistance in series with the one circuit or the other. It should not be connected inside the series field or compensating field shunts, if such are used. An equalizer cable is required in general, and this equalizer connection on the Ridgeway generator should be made between the armature and the compensating winding. To secure stable parallel operation, it is necessary that momentary swings of load from one armature to the other, do not result in corresponding changes in the series field currents. This requirement will be more fully met, the lower the equalizer resistance. For this reason, resistance should not be inserted in the equalizer to adjust the division of load between the machines. If both generators are adjusted to undercompound, successful multiple operation without equalizer can likely be obtained. In such a case, no attention need be paid to the question of making the compensating field and series field drops equal. The foregoing statements are general suggestions only. For more definite information, the manufacturers should be consulted. F.L.M.

THE ELECTRIC JOURNAL

VOL. XVI SEPTEMBER, 1919 NO. 9

The Association of Iron & Steel Electrical Engineers

The fundamental object of the Association of Iron and Steel Electrical Engineers has always been the advancement of the art of applied electrical engineering in the steel mills and allied industries. This object is being carried out more and more effectively under the direction of technical committees and by means of technical discussions, both in the section meetings and in the annual convention. By this interchange of experience each member receives some benefit from his connection with the association. The total amount of this benefit is dependent not only on what others do but largely on what each one does himself. That the Association is being appreciated more and more is shown by the continually increasing interest taken by members in the work of the Association, which in the last analysis has to do with the affairs of the steel mills, shops, foundries and allied industries.

This year the association is to hold its annual convention in St. Louis, September 22nd to 26th. The convention committee, with Mr. A. H. Swartz as chairman, has completed arrangements for the accommodation of Association members and is very enthusiastic over the wonderful co-operation of the St. Louis Chamber of Commerce and the local steel and electrical men. As an additional feature, an exhibition room adjoins that in which the meetings will be held, and from present indications the exhibits will be well worth while.

The Association is especially proud of its members who were "over there", doing their bit for the cause of right, and will take great pleasure in welcoming them home as they return to us, each with a new story and a bigger and better idea of the duty of the electrical engineer to his country, to his company, to his association and to himself.

The work of the past year has been quite satisfactory, both from the standpoint of accomplishment and quality. Mr. J. F. Kelly as permanent secretary, in his first year, has more than fulfilled the best hopes of the exponents of the idea, and through his efforts the effectiveness of the Association is increasing every month. The work of the sections has been better than ever before, and is rapidly becoming one of the most important phases of the Association's activity. The Philadelphia, Cleveland and Chicago sections all had a very successful year. The papers presented before these sections have been of a high technical character and the discussions broad and interesting. A new section was organized at Birmingham, Alabama, in March and has held one session. They are fully organized to start work this fall and, from the large number of enthusiastic members, a very successful year is predicted.

The by-laws governing the organization and operation of sections have been completely revised, making the term of section officers begin immediately after the last meeting held in the spring.

The officers of the sections are as follows:—

	Chairman	Secretary
Chicago Section	W. S. Hall	F. H. Semple
Cleveland Section	R. D. Nye	J. W. Spear
Birmingham Section	J. E. Fries	F. M. Sturgiss
Philadelphia Section	F. H. Woodhull	Lynn O. Morrow

The regular monthly meetings of the association held in Pittsburgh and Youngstown this year were well attended and the papers presented up to the usual high standard. The meeting at Youngstown deserves special mention, as it was made possible through the courtesy of the Brier Hill Steel Company. After spending the greater part of the day inspecting their new plate mill, a general discussion was held in the evening. This discussion covered all points of the mill and the members in attendance not only asked questions, but also offered suggestions as to the operation of the plant.

The committee work of the Association has been of a high standard. Special mention should be made of the safety committee, the educational committee, the standardization committee and the editing and papers committee. Each have performed their work well and have aided materially in raising the standard of association activities. The membership of the association has increased during the year and the 1000 mark will probably be passed before January 1920.

Among the innovations of the year is the monthly publication which carries the news of the Association as well as those papers presented in the various sections which have been passed by the editing committee. This monthly edition is to be greatly enlarged during the coming year and will be a great help in getting papers to the members more promptly than would otherwise be possible.

D. M. PETTY,
President,
Assoc. of Iron and Steel Electrical Engineers

Motor-Driven Steel Mills

Within the brief period of fifteen years, steel mill electrification has developed to a remarkable degree. To date, the list of motor-driven mills totals approximately 600, with a maximum of more than 900 000 horse-power and includes practically every type and size of steel mill. Though the capacity of the motor-driven mills is probably not more than 25 percent of the total, it is significant that a number of large plants are electrified almost 100 percent, and the majority of the mills installed during the last five years use electric drive.

The advantages of motor drive have greatly increased during the last five years with the gradual change of working conditions, such as labor and pace

of materials, and with the increased demand for steel products, regarding both quantity and quality.

Much attention has been given to plant design, management and operation to encourage the development of scientific methods, accuracy and general efficiency of plant operation. The "Safety First" idea is a matter of prime importance and has been of great benefit both to steel workers and steel companies.

Motor drive assists in making a plant a model one in every respect. Cleanliness, the absence of noise, the suitability of the motor characteristics for the working conditions, its reliability and the very limited attention required, alone are sufficient to warrant its first consideration in the building of a new mill or the improvement of an existing plant. But these features are quite secondary to the main advantages namely:—lower power cost; increased production; and the facilities offered for improvement of power conditions throughout the plant.

Much has been said concerning individual mill improvement as obtained by motor drive, but the most value and greatest return on the investment are only realized when the plant as a whole is electrified. The price of power is reduced to a remarkable degree with increased size of central power plant or the purchase of large blocks of power, and labor and the general expense of maintenance are decreased in many cases more than fifty percent and plant operation generally improved, with the very minimum of delays due to failure of apparatus or lack of proper capacity or other limitations. These facts are becoming well recognized and there is evidence that the electrification of steel mills will now be carried on according to a well-defined policy of broad plant development, including plans for several years in the future.

The large central power plant, (and this means 40 000 to 75 000 kw) and the use of large amounts of power from central station companies, are soon to be realities. With this development will come practically the universal use of motors, for under these conditions the first cost of installation and cost of operation will be so greatly in favor of the electric drive that the use of steam power will be practically prohibitive.

In the past but little attention has been given to the question of rehabilitation of existing mills. The first cost of the installation has been considered high, as it included a considerable charge for the power plant. Today this item is rapidly becoming of minor importance as the complete plant system of electrification is developed.

The present is a period when improvements of existing mills warrant fullest consideration. Many plants may not deem it advisable to add materially to their output, as the expense of adding to all departments may not be desirable. Improved plant efficiency, with lower cost of production, however, are matters of particular concern, with labor conditions rather unsettled, price of material high and general business prospects not above average. Perhaps it would be a good plan to plot a curve showing the actual working capacity of the various departments of the mill and of the machinery and see just what classification should be made regarding the changes; also the time required to build and install such improvements.

The main drive is often the limiting factor of the mill capacity. The unit may have outlived its usefulness, being badly worn and unsuited for the present day mill requirements. It is, in any event, taking a great deal more steam than is required for electric drive. In the average case for a reversing mill this amount is more than 100 percent. Since it requires several months to build and install a motor unit for a mill of large size, it seems advisable to give this item present consideration.

Orders for two units have recently been placed for reversing equipment which will supersede engine drive on existing reversing blooming mills. There never was a period when a saving in power costs represents such a large return on the investment as at present, especially in the case of reversing mills, and undoubtedly there are many existing mills of various types that could be greatly improved by electric drive.

The activities of the Association of Iron & Steel Electrical Engineers have been a material factor in the rapid development made in steel mill improvements during the last few years, as electricity has played a most important part in the advancement made. A great deal can be accomplished in the improving of existing plants and the work of the Association will be particularly helpful in this general plan of rehabilitation.

Brent Wiley

Electrical Development in the Iron and Steel Industry

Advancement in the application of electricity to the iron and steel industry has been so marked and so rapid that one is prompted to call it "phenomenal". This remarkable growth and the use of this form of energy for every drive in this industry has been brought about for three reasons, namely:—Economics; flexibility of application; the Association of Iron and Steel Electrical Engineers.

The first two reasons will be admitted. The third one immediately creates the question as to whether or not this statement is too broad and requires definition. The membership of this Association has contributed five thousand pages of both technical and practical reading matter, which we feel has been largely instrumental in assisting in the development of the iron and steel and allied industries to the highest state of electrical perfection, and has helped both to reduce costs and to increase production.

Twenty years ago the steel industry boasted of a few scattered auxiliary electrical drives. Today, more than 500 main rolls are electrified, including reversing blooming mills, billet and bar mills, plate mills, sheet mills, rod mills, merchant, wire, structural and rail mills, while the auxiliary drives number over a million.

We know of only one instance during the last year in the selection of a main roll drive, where the electric driven mill was not given preference. Probably initial cost determined this type of drive.

Some of the phases of the electrical advancement in the iron and steel mills which have recently come to the writer's attention, and which he feels are worthy of mention are, briefly:—

The installation of a remote control substation operating without attendants which, if adopted by one corporation alone as a standard, would mean an annual saving of possibly a million dollars.

A meter that measures gas electrically, which will not only help to produce quality pig iron but also quantity.

Blast furnace skip hoists driven by alternating-current motors.

Direct connected motors, driving blooming mill shears, using no fly wheel.

Electric furnaces for reducing ferro-alloys.

The installation of magnetic control in a pulpit arrangement whereby one operator may have complete control of all the motors driving an entire finishing mill.

Electrically-operated tractors.

The successful installation of a loop power transmission system which is operating with the highest degree of efficiency and satisfaction.

J. F. Kelly,
Secretary,
Assoc. of Iron & Steel Electrical Engineers

Thirty Years of Service to Electrical Industry

There are two principal periods or stages in any field of engineering; first, the pioneer stage, which is largely one of cut-and-try methods, second, the analytical stage, which follows sooner or later and which is, in certain ways, vastly more difficult. The pioneer period is usually the more spectacular one and not infrequently large reputations are built upon relatively small accomplishments. The analytical period, while less spectacular, is often the time of true development, odds and ends of the earlier period being brought together, along with further developments and combined into methods and machinery, so to speak, which enable the engineer, from his analysis, to predict hitherto unknown results.

The types of men who have succeeded in each of these fields or periods are, in general, quite different. Looking back, few of those who were prominent in the earlier cut-and-try stage have continued when the analytical period was really entered and, in the same way, many of the most successful analytical engineers have appeared since the pioneer stage. Apparently, the characteristics required for success in the two stages of development are quite dissimilar. In the electrical field, occasionally an engineer has been quite successful in both periods. Possibly this is because he has been primarily of the analytical type, tending strongly toward the methods of the later period, but has happened to begin his career during the early experimental period. In other words, he was out of his time at the beginning instead of at the end of his career.

Thirty years ago, such a young engineer came to Pittsburgh and began a busy career which has made him known the world over. Mr. Benjamin G. Lamme, Westinghouse chief engineer, now in the prime of his active service in the industry, began work in the test room of the Westinghouse Company in 1889 and his earliest endeavors were along experimental lines, as was all such work in those days. During the next year he was using mathematical analysis to a certain extent in carrying on his work, and in the following few years, developed methods of calculation and analysis which are used most extensively in the entire organization at the present day. This, therefore, classifies him at once as belonging to the present or analytical period and all of his later work strengthens this opinion, although some of his earlier inventions still stand out prominently in the popular recollections.

In the first two or three years of his service with the Company, he wrote many technical papers for the use of his co-workers and assistants, but it was not until 1897 that he began to prepare technical papers for the public. In that year, his first published technical paper was presented before the National Electric Light Association Convention at Niagara Falls. This was his well-known paper on "The Polyphase Motor", which has since been printed and reprinted many times to meet the demand for a technical discussion of a non-mathematical type, which would give a clearer insight into this difficult subject. This paper was followed during the next few years by others for various engineering and technical societies and for engineering journals. These papers excited considerable interest and a number of them have been reissued in pamphlet form in order to meet the continued demand. However, in general, his papers have been scattered in various publications so that very few have had the opportunity to read more than a limited number of them.

In view of this fact, the Westinghouse Company, as an expression of its appreciation of Mr. Lamme's thirty years' continuous service, arranged to collect his most valuable technical papers in one volume which would be made available to the public at a very nominal cost for a work of this character and size. This book, entitled "Electrical Engineering Papers" contains thirty-one complete articles, totalling 773 pages, all of which are quite readable by the average engineer, due to the absence of visible mathematics as well as the clarity of expression of the author. Practically all of the articles are of an educational nature, the last two in the volume covering in particular matters of engineering education. There are also included several historical papers covering early history and data which is not available elsewhere.

Mr. Lamme has for years personally supervised the training of a number of young engineers, and has taken great interest in their development. Such personal attention must necessarily be limited to a few and it is therefore believed that the publication of the present book will be of great benefit to the younger generation of engineers, by placing them in close contact with the methods of thinking and ways of attacking the many problems which have been solved by this eminent engineer.

A. H. McIntire

Electric Furnaces for Steel Foundries

With Historical Introduction

W. E. Moore
Pittsburgh Electric Furnace Corp.,
Pittsburgh, Pa.

THE electric furnace is an old and well known invention. However, it has attained commercial importance only in the past 25 years, and for steel making, its commercial importance in America dates back no further than about six years.

In 1800, Dr. Volta invented the electric battery and Sir Humphrey Davey began experimenting with electric arcs and the electric furnace, in a miniature way, and continued to 1810. In 1815, Pepys, an Englishman, built an electric furnace and converted wrought iron into steel by the cementation process, using electric heat. In 1839, Robert Hare of Philadelphia, made an electric furnace and produced calcium carbide therein in a small way, and he also graphitized carbon. All of these experiments were with battery-generated power, very expensive and obtainable in small quantities only.

The year 1867 saw the invention of the dynamo electric-generator, which immediately made available larger supplies of cheaper electric power, which greatly enlarged the field for experiments. William Siemens of London, in 1878, read a paper before the Society of Telegraph Engineers on his electric steel furnace, and from 1880 to 1882 continued his experiments making steel in heats as large as 100 lbs. and in some experiments melting as much as 8 lbs. of platinum. His furnace was of the direct arc, single electrode type, since known as a Siemens furnace, and consisted of a carbon electrode projecting down into a graphite crucible containing the charge. Direct current was used, developed from an individual generator of variable voltage. Indeed, all initial furnace experiments, both in this country and abroad, were made with direct-current.

Cowles, of Lockport, N. Y., in 1885, made a double carbon electric furnace and produced aluminum-copper-steel and other alloys from their ores.

In 1886 the invention of the aluminum furnace was made simultaneously by Hall in America, and Heroult, in France. This furnace was heated by what is known as the resistance method, using direct current, and aluminum was deposited electrolytically from the molten bath of its ores, fluxed with Greenland Kryolite. When the Aluminum Company was first formed, its principal officer reports that had they been told that they must sell aluminum at less than $5.00 per pound, they would have abandoned the enterprise. Indeed, their first purchase was a large safe in which their daily production of aluminum was to be locked up each night, as a rare metal. The electric furnace, since it has been fully developed, has so far reduced the cost of aluminum that the commercial selling price in America has been as low as 18 cents per pound, and still lower abroad. These furnaces now operate at an efficiency of

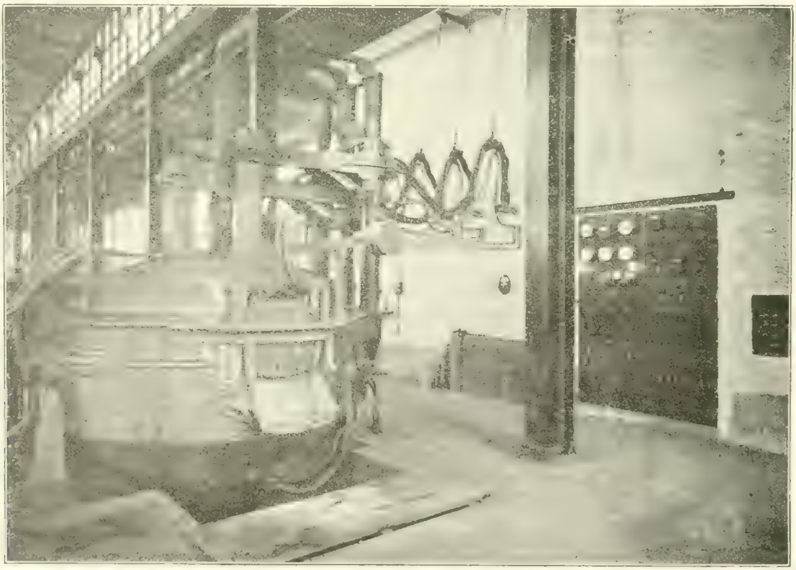


FIG. 1– THREE TON ELECTRIC STEEL FOUNDRY FURNACE, SWITCHBOARD AND REGULATORS

about 1.5 lbs. of aluminum per horse-power-day. The aluminum production in 1884 for our entire country was estimated at 225 lbs. made by the chemical process; now the production is estimated at over a million times as much per annum.

The year 1892 saw the inauguration by Moissan in Paris of his classic experiments with electric furnaces, in which he made carbides, reduced many metals from their ores and wound up with the spectacular performance of manufacturing diamonds of miniature size. These experiments were widely published and greatly broadened the interest in and knowledge of electric furnaces, though he produced no direct commercial results.

In 1892, Wilson of Canada, began experiments with the arc-type furnace and smelted aluminum in a plant on Smiths River, at Spray, N. C. This plant consisted of a 300-hp. water-wheel belted to a 60-volt direct current, variable voltage generator supplying power to a small arc furnace, which was constructed in several types and of various forms. It was here that the first large ammeter was used—a Weston instrument of 3000 amperes capacity. The furnace used most consisted of a carbon plate, forming the bottom electrode, upon which was built a firebrick crucible into which was suspended a 6-in. carbon electrode, hung from a jib crane by an ordinary chain hoist, the arc length being regulated by the chain hoist. The purpose of this enterprise was to smelt pure aluminum from its ores, but it was unsuccessful for that purpose, though various mixtures were smelted, such as alloys of copper and aluminum. In some experiments, tool steel, said to be of excellent quality was, in a small way, manufactured, using an electric furnace in which there were two suspended carbon electrodes arcing from one electrode down to the metal bath, through the slag and out through the other, thus in a small way anticipating the Heroult steel-making furnace, which later became so well known as a pioneer in the steel industry. When experimenting with various fluxes, such as lime and carbon, in the attempt to reduce aluminum from its ore (bauxite) the slags from unsuccessful experiments were thrown out on the wet ground immediately below the canal and showed a gas development which, upon examination, was found to be acetylene. Another accidental product was fused alumina, the modern abrasive known as aloxite. This was the beginning of the calcium carbide and ferro-alloy industry. The carbide industry which developed from these experiments brought into use the first large commercial application of electric furnaces in a plant built at Niagara Falls, originally using 20 000 hp. Thereafter, the carbide industry spread to Canada, Scotland, Norway, Germany, and the Alpine regions.

By the year 1909 the carbide industry had been largely overdone both in America and in Europe, and many of the carbide producers turned their attention to ferro-alloys and other alloys, manufacturing with practically the same furnace plant ferro-alloys of chromium, silicon, manganese, molybdenum, tungsten, etc. These alloys were of such very high purity that they rapidly came into extended commercial use throughout the country, especially for use in connection with the higher grades of crucible and alloy steels and are largely responsible for the splendid steels which made the automobile and aeroplane possible. Thus the electric furnace has introduced a new era in the manufacture of fine steels.

Up to the present time the electric furnace has seen its largest commercial development, first in the manufacture of aluminum and second in the manufacture of steel; and the second development is rapidly overstepping the first. In 1913 there were only 19 electric furnaces making steel in America; this number had increased to 136 at the end of 1916, and to 269 at the end of 1917, at which time it was estimated the world had a total of 733 electric steel making furnaces, turning out annually four million tons of steel, of which America produced approximately one-half. Now there are about 1000 steel furnaces in use.

Electric steel making furnaces are divided into two general classes, namely, basic or magnesite lined and acid lined. Acid furnaces are those lined with silicious refractories and are used for melting and alloying steel which is made from a high grade of scrap, where the sulphur and phosphorous impurities are so low that further refining is not deemed necessary, as in making steel castings. It is, however, possible in a properly operated acid furnace to reduce the percentage of such impurities by a small percentage (say 10 to 15 percent) only.

With basic furnaces the refractory linings are much more resistant to the lime slags which are carried as a molten blanket on top of the steel bath for the purpose of taking up and fluxing out the sulphur and phosphorous. Phosphorous is removed at the first operation; high calcium slags, when in contact with metal under oxidizing conditions, as when iron ore or mill scale is added to the bath and at not too high temperature, have a strong affinity for phosphorous which is quickly absorbed by the slag during that period of the heat known to the melters as the "boil." The phosphorous from the metal is thus oxidized into phosphoric acid and then converted into phosphate of lime, in which form it is a stable constituent of the slag, provided the temperature is not carried too high. This first or oxidizing slag is then skimmed off and another slag is made by adding lime and carbon, which is fused by the heat of the arc. This slag then forms calcium carbides, or the "carbide slag." Carbon such as granular coke, retort-carbon or anthracite coal is used with high calcium, low magnesia, lime. This carbide slag under high heat and in a reducing atmosphere has a strong affinity for and carries off the sulphur from the steel, which is absorbed by the slag in the form of calcium sulphate. From very impure scrap, it is thus possible (though not always commercially practicable)

to make a very high grade of tool steel in an electric furnace which heretofore could be made only by melting the purest forms of Norway or Swedish iron, and then only by melting in crucibles, which is a very slow and expensive process.

Primarily, electric steel became popular for its superior physical properties. While such steel can be made with a more satisfactory chemical analysis, using a given grade of raw materials, than by other processes, experience has abundantly demonstrated that when made to the same chemical analysis, it will average about 15 percent greater tensile strength or ductility, depending upon its heat treatment, and is more resistant to shock and better able to receive heat treatment. The

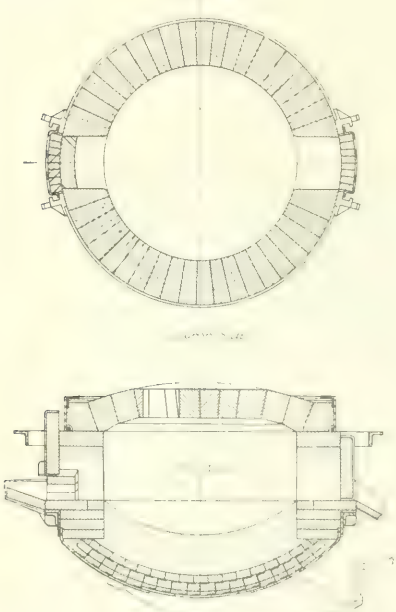


FIG. 2—SECTIONS OF FURNACE SHOWN IN FIG. 1
Showing neutral connection to bottom of furnace.

reason for this is that the steel, being made in a closed furnace and in a reducing atmosphere away from the contaminating influences of combustion gases, is more solid, freer from gases and less prone to inclusions of slag oxides, etc. As an example, the tests in Table I made by R. W. Hunt and Company, Chicago, Jan. 30, 1919, for the Chicago Surface Lines, illustrate the physical properties of A. E. R. A. specification heat treated electric furnace axle steel. It was heated to 1450-1460 deg. F., held one hour, quenched in 65 deg. oil, drawn at 1185-1200 deg. F. for one hour and then slowly cooled in the furnace. The open-hearth steel was also heat-treated in the same manner.

Being absolutely dead when properly made, and averaging lower in sulphur, electric steel in the foundry is less liable to show shrinkage cracks between ribs of castings and, being more fluid, it is not so liable to piping or blow holes.

The electric furnace is especially useful for making alloy steel. Since the metal is treated in a reducing atmosphere, there need be no large losses of the alloys such as silicon, manganese, vanadium and chromium, which in the ordinary open-hearth practice are oxidized in large quantities and carried to waste in the slag, thus producing uncertain mixtures. Indeed, alloys in open-hearth practice frequently show losses of 40 to 50 percent, while in the electric furnace they will be practically nil.

With the electric furnace it is much easier to carry the finishing operation to a more nearly exact limit on carbon or silicon content, than is practicable in the case of the open-hearth furnace, and finish with an absence of gases of solution and inclusion, such as oxygen and nitrogen.

In open-hearth furnaces it is impracticable to melt down fine turnings in quantity for the reason that the oxidizing flames, which furnish the heat to the furnace, will reduce the metal when in an attenuated form to a mass of oxide before it becomes molten, whereas with the electric furnace it is entirely practicable to melt

TABLE I COMPARISON OF OPEN HEARTH AND ELECTRIC FURNACE STEEL

	Open Hearth	Furnace Electric
El. limit per sq. in.	41 060	64 850
Ten. strength per sq. in.	80 100	105 140
Percent elongation in 2 in.	21.5	22.0
Percent reduction of area	31.74	52.37
Elastic torsion	10 750	33 700
Character of fracture	Granular	Silky Cup

turnings, which under ordinary market conditions are purchaseable at about five to ten dollars per ton lower price than the heavy melting grade of steel required in open-hearth practice.

In the electric furnace it is practicable to obtain a heat transfer efficiency of 60 to 70 percent, that is to say, 60 to 70 percent of the heat energy of the electric power supply may be put into the molten charge, whereas with open-hearth practice, the efficiency ranges from eight to fifteen percent and in a crucible furnace from two to six percent. The fuel developed heat unit at the open-hearth furnace is, however, bought in a much cheaper form than the heat unit supplied as electric power and if the electric furnace did not have the other advantages mentioned, it could not at present compete against the open-hearth furnace in the cost of heat energy.

On account of the very intense heat of the electric arc, it is entirely feasible to melt down quite rapidly; thus in the electric furnace it is possible to melt down and refine a charge of casting steel in two hours, or less, which in the open-hearth furnace might require ten to fourteen hours. In other words, a twelve-ton electric furnace may be practically equivalent to a sixty-ton open-hearth furnace, so far as steel output is concerned. A twelve-ton electric furnace, of course, re-

quires a correspondingly smaller ladle, crane and building structure, for it is the practice to tap the entire heat into one ladle with either type of furnace.

The arc-type of electric furnace is practically the only one being installed for steel making today; however, there have been a few of the induction-type furnaces constructed. At first glance, the induction-type furnace appears to have many advantages over the arc-type furnace, but practice has shown that it is in no wise a competitor of a properly constructed arc furnace, as on large sizes the power--factor is extremely low and the efficiency of the furnace, owing to the cost of replacing the refractories, is also low. It is also not so good a refining furnace as the arc-type.

Arc furnaces may again be classified into the long arc and short arc types. There are many theoretical inducements to use the long arc furnaces, for with a given energy input, the electrode is correspondingly smaller and the electrode cost is therefore reduced proportionately. With the water cooled bottom contact type furnace, either the furnace size must be kept small or the voltage must be greatly increased in order to keep the current low and prevent that form of contact from overheating, so it is the custom to operate the bottom electrode furnace with quite a long arc and low current.

Arc furnaces may again be classified into single-phase, two-phase, and three-phase types. The single-phase furnace is ideally simple, but is poorly adapted to modern power plant conditions, as central station power today is universally generated and transmitted at three-phase. The long arc single-phase furnaces, too, have the very great disadvantage of operating on extremely low power-factor, thus causing a great waste in transformer, line and generator capacity, which usually makes them prohibitive from the central station man's viewpoint in any but quite small sizes, say one-fourth to one ton capacity per heat.

The two-phase furnace may be operated either from two or three-phase power, but when operated from three-phase power, the phases have to be transformed by Scott connected transformers, which are more costly and less efficient than for the straight three-phase conversion, and frequently unbalance the power system. The two-phase furnace is usually built with two or four arcing electrodes and while it gives a theoretically balanced load on the power system, it has the objection of requiring an additional electrode, which increases the electrode consumption 33 percent over the three-phase furnace.

The three-phase furnace for installations of moderate and large size is the most universally satisfactory and popular furnace, fulfilling all the conditions as to balanced load and high power-factor required by the central stations, at the same time giving the minimum electrode loss and the simplest form of electrode automatic adjusting gear.

It is possible to obtain satisfactory operation of the direct-arc type furnace for melting the non-ferrous metals where the content of metals which volatilize at low temperatures is small, as for instance, in making bronze and bearing metals. But where the zinc or aluminum content is high, such as in yellow brass, Muntz metal, etc., the direct-arc type furnace is highly unsatisfactory and results in great waste of the more volatile metals, and the making of porous castings, unless special means are provided to overcome highly localized heating. Consequently, special furnaces of the resistor, rocking, rolling, tumbling or other types are required for brass melting.

The crucible furnace is the oldest method for making steel castings and of making first-class tool steel. It has now, however, been practically eliminated by the electric furnace, which has many advantages in rapidity and in reduced cost, as well as its ability to make more sound castings. The cost of crucibles and fuel alone in crucible steel foundries frequently runs up to three cents per pound. With crucible steel the heats are of such small quantity—100 to 200 lbs. per pot—that the contents of several pots must be combined into one ladle to make the casting of ordinary size. Sometimes the different pots of steel are of such different compositions as to cause the ladle to boil when they are combined, tending to make unsound castings.

Due to the absorption of carbon from the crucible,

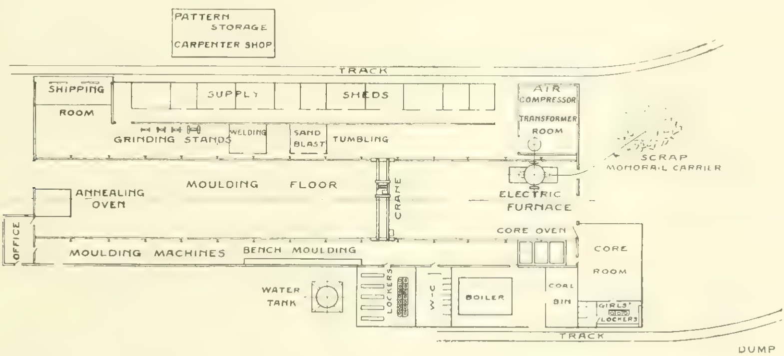


FIG. 3—PLAN OF TYPICAL ELECTRIC STEEL FOUNDRY FOR SMALL CASTINGS

it is difficult to make castings low enough in carbon to obtain the ductility desired for many purposes. Furthermore, the steel reduces the silica from the clay of the crucible, tending to run the silicon content of the product high. The overpowering objection to the crucible process is, however, the high cost of the product due to:—

a—High cost of pure melting stock, as no refining is practicable.

b—Very high labor cost on account of the small heats handled.

c—Crucible furnaces are notoriously extravagant in fuel consumption, sometimes using three tons of coal per ton melted.

d—High cost of crucible renewals, often averaging two to four crucibles per ton melted at a cost of $9 to $11 each, or $18 to $44 per ton for crucibles alone.

For these reasons the crucible melting shop is rapidly going out of use for castings, as well as for tool steels.

During later years the side-blow converter process has become very popular in steel foundries making castings of medium and small size. In this process high grade, high silicon, low phosphorous and sulphur pig iron is melted in a cupola furnace with the finest grade of coke obtainable. The quite hot liquid iron is then tapped into a ladle, transported to and dumped into the convertor. The convertor is then tilted until the blast tuyeres, which enter at the side of the vessel, are turned down to blow directly onto the surface of the metal. The blast, which is generally from a Root-type blower is then turned on, impinging sharply against the surface of the metal, which is thus violently agitated and oxidized.

The air blast burns out the silicon and then the carbon, the products of combustion being CO_2 and SiO_2. This combustion greatly increases the heat of the metal, as brought from the cupola. When the process has proceeded far enough, which the operators guess at from the drop of the flame, the ferro-alloys are thrown into the bath to reduce the oxides, neutralize the sulphur, and kill the steel, which would otherwise be wild, i. e., full of effervescing gases, when poured. It would also be hot short, that is, prone to crack when freezing in the molds, unless doctored liberally by the addition of manganese, as the converter effectively burns out the manganese of the pig iron charge.

The steel is then dumped from the converter into a bull ladle into which aluminum amounting to one to three lbs. per ton has been charged; it is transported by traveling crane directly to the larger molds, or to be shanked off into the smaller molds by small hand shank ladles.

The advantages of the converter process are: The steel may be made quite hot and fluid enough for quite thin castings; the heats, usually running one to two tons, are of convenient size to be poured off quickly before cooling; the fuel consumption is moderate, though rather higher than for the cast iron melting cupola, averaging 400 to 600 lbs. of coke per ton; the first cost of the apparatus is low and the process is available for intermittent service.

The disadvantages are: The metal must be handled twice in the ladle; the metal picks up sulphur and phosphorous and nitrides from contact with the fuel and the air blast; the losses in the cupola and converter are quite high, running from 16 to 24 percent, further concentrating and increasing the percentages of impurities in the original metal and wasting costly melting stock; the steel is full of oxides and gases and requires large quantities of expensive ferro-alloys to kill; the quality of the steel physically, as well as chemically, is below par; a heat once blown too cold cannot again be brought up in heat enough to cast and must be pigged; only the highest grades of melting stock may be used, costing generally $15 to $25 per ton more than for the acid open-hearth furnace and $20 to $35 per ton more than for the electric furnace; the refractory maintenance is high, as the cupola and converter linings must be repaired after each 10 hours run. Liquid metal costs of converter steel frequently run up to $60 or $80 per ton.

The electric furnace is the newest steel producing agency and is gaining in popularity more rapidly than all others. It is the most compact furnace, and the rapidity with which it will melt down cold charges adapts it splendidly to the making of steel castings. It is the cleanest and most certain method of making steel, and its small bulk makes it feasible to locate the furnace near the center of the floor where the metal need be transported short distances only. The size is small and convenient and the heats come rapidly, so that no large floor area need be tied up in molds per heat, and it works out to best advantage on the foundry floor area.

The arc-type furnace is best suited for foundry work and the most popular size has a capacity of three tons per heat, though sometimes 1.5 ton furnaces are required. The more highly powered and rapid furnaces for such work turn out eight to twelve heats per 24 hours, and with a power consumption of 500 to 650 kilowatt-hours per ton of liquid steel, and considering the ultimate efficiency of the large modern turbo-generator power house, at, say, 1.5 lbs. of coal per kw-hr., its fuel consumption might be said to be the equivalent to 750 to 900 lbs. of coal per ton, and the coal need not be of high grade, nor low in sulphur and phosphorous as is necessary with fuel fired furnaces.

Since the charge is melted in a reducing atmosphere, there is practically no oxidation of the metal; consequently thin scrap or light, fluffy turnings or scrap of other forms, such as can be conveniently charged into the furnace, may be melted. Such scrap on the present market sells for approximately five to ten dollars per ton less than low phosphorus, heavy melting scrap necessary with the ordinary acid open-hearth melting furnace installation.

The furnace atmosphere, being of a reducing nature, makes it easier to refine and kill the steel, re-

sulting in a saving amounting frequently to half of the ferro-alloys necessary with converter steel, effecting a saving of say two dollars per ton. The melting losses in the electric furnace are much the lowest of any modern process, averaging two to five percent as against six to nine percent in the open-hearth and 16 to 24 percent in the converter process.

The electric furnace does not contaminate the metal as with fuel heated furnaces and an acid electric will therefore readily make No. 3-U.S.A. specification steel, where it is nowadays practically impossible to find melting stock sufficiently pure to do so with the converter process. The saving alone in the cost of melting stock will more than pay the entire conversion cost of electric steel. The deader, more dense electric steel yields a larger percentage of good castings and the lower sulphur renders the castings free from shrinkage, flaws and cracks, while the hotter and more fluid steel renders possible thinner weight and lighter sections than can be produced commercially by other processes. The greatest points in favor of the electric furnace are the much higher grades of castings produced, and the higher percentage yield.

TABLE II—AVERAGE COST PER TON FOR TWO TONS OF CONVERTER STEEL DIVIDED INTO FOUR CUPOLA CHARGES

Two Ton Converter — Charge	Lbs. per 2 Ton Blow	Price per Net Ton	Cost per Charge	Cost per Ton of Liquid Steel
Low phosphorous pig iron	1127	$50.00	$28.18	$14.09
Bessemer pig iron	1127	28.00	15.78	7.89
Steel scrap	2254	18.00	20.29	10.14
Silicon and Spiegel	370	60.00	11.10	5.55
Coke—863 lbs.		7.00	3.03	1.01
Total weight of charge	4878			
Included above for 18% conversion losses	878			
Cost of material per ton of liquid steel				$38.68
ADDITIONS PER TON OF STEEL				
10 pounds 80% ferro manganese @ 6c				0.60
6 pounds 50% ferro-silicon @ 5c				0.30
2 pounds aluminum @ 30c				0.60
Power for blower motors				1.25
Cost of materials and power per ton of liquid steel				$41.43
Average cost cupola and converter linings				1.20
Labor costs				3.00
Cost of converter steel per net ton in ladle				$45.63

With the electric furnace, foundry men can more readily make and check their steel to an exact percentage of carbon, manganese and silicon, and can more easily keep the undesirable sulphur and phosphorous to low limits than by any other process. The steel may be readily alloyed with nickel, chromium and vanadium to make the higher grades of steel castings to replace forgings and for special purposes, such as may be required for parts of unusual strength, ductility or for cutting tools; it is thus entirely feasible to make castings which will run up to an ultimate strength of 130 000 lbs. per sq. in., or to cast high-speed steel milling cutters and reamers. The figures in Tables II and III show present-day comparative operating costs for liquid steel in the ladle under favorable conditions.

The acid open-hearth furnace is still frequently used, generally with oil fuel and mostly in foundries making the heavier classes of steel castings. With the acid open-hearth furnace, the standard price must be paid for 50 percent of the charge in low-phosphorous heavy-melting scrap and 50 percent of the charge in Bessemer pig iron. The fuel oil consumption for such open-hearth furnaces in foundries usually runs from 45 to 90 gallons, costing at the present time from $3.37 to $7.50 per ton of liquid steel. In the largest of the steel foundries, it is true, producer-gas is frequently used at less fuel cost. However, the contaminating effect of the sulphur content of the coal and the complications and expense of the producer-plant as a rule deters the ordinary steel foundry from using coal producer-gas as open-hearth fuel.

The great drawback to the open-hearth furnace is the high cost of melting stock and its well known inability to furnish steel sufficiently hot to make medium and small castings satisfactorily without undue costs for refractories and largely increased fuel consumption. The inconvenience of large heats from the open-hearth furnace, 15 to 40 tons, counts heavily against it for small casting work.

TABLE III—AVERAGE COST PER TON FOR THREE-TON ACID LINED, RAPID TYPE, POLYPHASE, ELECTRIC FOUNDRY FURNACE STEEL

Three Ton Electric Furnace — Charge	Pounds Charged per 3 Ton Heat	Price per Net Ton	Cost per Charge	Cost per Ton of Liquid Steel
Axle turnings	6200	$12.00	$37.20	$12.40
(Included above 3% losses = 200 lbs.)				
Mill scale	100	5.00	0.25	0.09
(Included above 60% losses — 60 lbs.)				
Electrodes @ 7c	60		4.20	1.40
1650 kw-hr. (550 per ton) @ 1c per kw-hr.			16.50	5.50
Losses in melting—260 lbs.				
80% ferro-manganese	20	120.00	1.20	0.40
50% ferro-silicon	15	100.00	0.75	0.25
Aluminum @ 30c	1.5		0.45	0.15
Cost of material per ton of liquid steel				$20.19
Average cost of linings and roofs				0.40
Labor cost on furnace attendance				1.00
Cost of electric steel per net ton in ladle				$21.59

As to the most suitable type of electric furnace for installation in the ordinary steel foundry, if the scrap is inferior and high in sulphur and phosphorous, then the extra cost, slower operation and shorter refractory life of the basic furnace must be endured to obtain the lower limits of sulphur and phosphorous not practicable to reach with the acid furnace using commercial grades of scrap. At present the call is for acid-lined furnaces, and cheap, good scrap is available in large quantities. The acid furnace is simpler, cheaper and faster to operate, and the steel casts more easily.

It is nevertheless strongly recommended that a furnace be purchased so designed and constructed that it is adaptable to basic operation. This means that the furnace shell must be of large diameter and the bath

must be of large area and shallow. The furnace should not, it is thought, be of the long arc type, nor of the small diameter shell deep-bath type, if the best and most rapid work is contemplated. Indeed, even for acid melting there is a noticeable difference in the quality of the steel obtained from the large diameter, shallow-bath furnaces compared with that made in the deep-bath type furnace, for with the latter, it is not feasible to obtain the same mechanical reactions from the additions put in to refine and kill the steel, as when the bath is of the shallower type. Nor is it possible so thoroughly to deoxidize the metal by maintaining a reducing atmosphere in the furnace.

For rapid work, it is especially important to have the furnace constructed with all possible operating conveniences and facilities, so that one heat may follow another with the utmost rapidity and with a minimum loss of time for the necessary furnace adjustments. It is therefore important to look carefully to the facilities for making bottom and fettling the banks.

It is quite important that the furnace should operate at the highest practicable power-factor that can be obtained without undue disturbance of the power company's load, for by so doing the electrode, transformer, line and generator losses are maintained at a minimum. Engineering skill of a high order is required to forecast and select the best type of equipment, under the many varied power supply conditions which obtain in different localities.

By reason of the now generally acknowledged superior quality of the electric furnace product, greater flexibility of operation, quicker, more convenient sized heats, saving in alloys and in cost of melting stock, the electric furnace is rapidly coming to the front in the steel foundry wherever suitable power is available and progressive policies are in vogue. It is making possible the profitable operation of widely distributed small steel foundries to an extent not generally realized.

Power companies dislike to receive a single-phase or unbalanced load. They either refuse to handle such a load at all or penalize the user by charging a higher rate. It is, therefore, essential that furnaces above the smallest sizes, say three-eighths ton capacity or less, be arranged to receive a balanced polyphase power supply.

For the manufacture of tool steel, no other process can beat the electric furnace on quality, and for crucible steel the cost of the crucibles alone is more than the entire conversion cost of the electric furnace steel, to say nothing of the enormously cheaper melting stock used in electric furnaces for making the finest tool steels.

It is often asked when the electric furnace field will become saturated and electric furnaces no longer desirable purchases. The natural growth of the high-grade, medium and small size steel casting business will undoubtedly continue for years to come and demand the installation of a large number of electric furnaces. The crucible will probably disappear from the tool steel business, and the electric furnace will replace the open hearth furnace in the manufacture of alloy, and the finer grades of carbon steel. There is a rapidly growing demand for the superior quality of cast iron and the finer grade of malleable iron produced by the electric furnace. And there is a further wide field for the electric furnace in the melting of brass and other non-ferrous metal, where the lower costs and enormous savings in volatilization losses are just beginning to be understood and appreciated.

The Manufacture of Ferro-Alloys in Electric Furnaces

C. B. Gibson

The large expansion in the iron and steel industry during the past few years has caused a corresponding increase in the use of ferro-alloys. With the enormous demand for tool, alloy and munition steels, and with the shutting off of certain alloys and raw materials previously obtained abroad, their demand has been stimulated greatly and their production increased to a very marked degree.

The expansion in ferro-silicon has been approximately 100 percent and the United States now leads, with an annual producing capacity of approximately 100 000 tons. This country also leads in ferrotungsten, and considerable progress has been made in ferrochrome and ferromanganese. Previous to the war approximately one-half of the ferrosilicon and ferromanganese was imported, as well as considerable ferrochrome. The increased production demanded in ferro-alloys has increased the number of electric furnaces, not only on work where they were already in use, but where prior to the war they had not been used or only to a limited degree.

Ferro-alloys are of the greatest importance to the steel industry and are used either to deoxidize the metal or put into the steel a certain percentage of the alloying metal, which imparts to the steel certain physical properties.

The demand for alloy steel is rapidly increasing, due to a large extent, to the requirements of the automobile, airplane and ordnance purposes. Specifications for steel are becoming more rigid, and the public is insistently asking for higher quality, and safety cannot be measured by price. These steels require large quantities of ferro-alloys. With cheaper ferro-alloys there is the possibility of cheaper alloy and tool steels, also

of improved quality in the steel by the use of ferrouranium and ferrozirconium.

A ferro-alloy, as the name implies, is an alloy of iron with some other metal and the steel maker uses it for one of two purposes:—either as a cleansing and deoxidizing agent, the alloy combining with the oxygen or other impurities of the bath and passing off in part or entirely in the slag; or for injecting into the steel a certain percentage of the alloying metal in order to give it certain physical properties, the characteristics of which depend upon the kind of alloy used. A large number of ferro-alloys are being produced commercially.

ALLOYS COMMONLY USED

Ferromanganese is the most essential ferro-alloy in steel manufacture and more ferromanganese is used than any other alloy. The greater part of the output of ferromanganese is used in the deoxidation and recarburization of ordinary steels produced by the Bessemer and open hearth processes. Steel of the best grade cannot be made without manganese, as the small percentage of manganese (from 0.25 percent to 0.8 percent) which remains in steel after deoxidizing with ferromanganese, seems to strengthen it in a way no other alloy will do.

Another constantly growing use for manganese is as a fixed addition in the production of manganese steel. After proper heat treatment, steel containing 12 percent to 13 percent manganese is so hard that machining is impractical, but it is as ductile as soft carbon steel and has a tensile strength about three times as great.

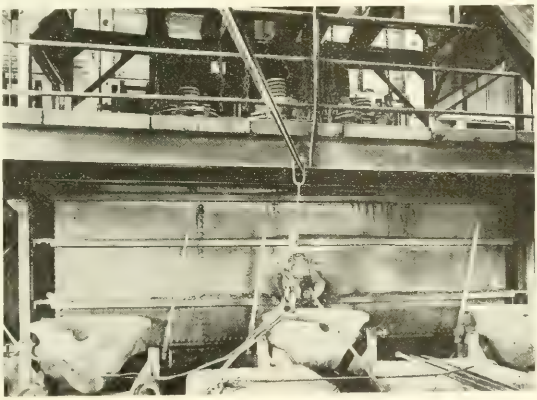


FIG. 1—1500 K.V.A., THREE-PHASE, FERRO-ALLOY FURNACE

Before the war, standard commercial ferromanganese contained 78 percent to 82 percent manganese and 5 percent to 6 percent carbon. During the war the standard was lowered to 70 percent manganese. Since the signing of the armistice most manufacturers have produced 78 percent to 82 percent alloy, and quotations are now made on both grades.

A low grade of ferromanganese, known commercially as spiegeleisen, or simply as spiegel, is used considerably in the production of Bessemer steel. Spiegel runs 15 to 20 percent manganese and is a rather cheap blast furnace alloy. There is seldom any effort made to produce it in an electric furnace.

Ferrosilicon is used principally in the steel industry as a deoxidizer, somewhat similar to ferromanganese. Ferrosilicon is about four times as active as ferromanganese, and is of vital importance in removing gasses that might form blow holes in large steel castings. In actual practice it is common to use ferromanganese for a major portion of the deoxidizing of casting steel and then finish the elimination of gases with ferrosilicon. An excess of ferrosilicon usually reduces the ductility of the steel, whereas an excess of manganese does not do so to as great an extent.

A special steel, called silicon steel, in which the silicon is used as a fixed addition, usually contains about 2.75 percent silicon. After a double heat treatment this steel has a higher magnetic permeability than pure iron, but also has a high electrical resistance. As a result of its high permeability it has a low hysteresis loss, and is used considerably in electrical machinery.

Ferrosilicon runs from 15 to 90 percent silicon, but two standard grades running respectively 50 and 75 percent silicon are recognized and regularly quoted in the metal market. A 10 to 15 percent ferrosilicon is made in ordinary blast furnaces, but the electric furnaces must be depended upon to produce all of the higher grades.

Ferrochrome is used for making what is commercially called chrome steel, chrome-vanadium steel, high-speed steel and chrome nickel. The alloy is not used as a deoxidizer, but to impart definite characteristics to the steel. By properly proportioning the amount of alloy, ferrochrome will permit steel being made very hard, tough and resilient. Chrome steel is used for bar mill and stamp mill parts. Cutlery steel contains 10 to 12 percent of chromium. Chrome nickel steel contains about 1.5 percent chromium and is manufactured into armor plate and artillery. Chrome-vanadium steel consumes half the production of ferrochrome in automobile manufacture. This steel contains about one percent chromium. All high speed steel contains from four to five percent chromium in addition to other rare metals.

Commercial ferrochrome is sold entirely on the basis of its content of chromium. The usual market standard is an alloy with 60 to 70 percent chromium. Chromium has a great affinity for carbon and especial efforts must be made during its production to keep the carbon content of the alloy low enough so that it will not introduce objectional carbon into the finished steel. For this reason ferrochrome with a given percentage of chromium content will bring a higher price if the carbon content is low. Standard market products run

about six percent carbon. Over eight percent carbon is undesirable for most purposes.

Ferrotungsten is used for the addition of a fixed quantity of tungsten to steel. Tungsten is established as the most important ingredient in high-speed steel. Tool points of tungsten high-speed steel can be run so fast that they become red hot from friction and yet do not become soft. Apart from its use in tool steel it is used in ordnance and other places where a hard surface similar to that obtained by chilling is desirable. A small amount of tungsten is used in steel for permanent magnets, and it formerly was used in self-hardening steels, which are no longer made to any extent. Self-hardening steel does not possess the quality of holding its temper at high temperature, and has a cutting speed only slightly greater than carbon tool steel. It is called self-hardening because it is hard without being heat treated.

Commercial ferrotungsten runs 70 to 80 percent tungsten and less than one percent carbon and is purchased on the basis of tungsten content. Ferrotungsten with over one percent carbon is not marketable.

Ferromolybdenum has not come into general use in the steel industry in the United States, but has been used extensively in Europe. Previous to the war the main use of molybdenum was as a substitute for tungsten in high-speed steel. Only one-third or one-half as much molybdenum is necessary for this purpose; that is, where regular high-speed steel contains 17 percent, tungsten, six percent to nine percent molybdenum may be substituted. Proper heat treatment is necessary to give the desired quality. During the war a considerable quantity of molybdenum was used in steel for lining guns. A new use was developed, which may increase the market considerably, as a substitute for chrome-vanadium steel in automobile manufacture. Both for gun linings and automobile construction a very small percentage of molybdenum is used in the steel. It has also been used to a limited extent in making cylinders for internal combustion engines.

Commercial standards have not been very well established on ferromolybdenum. The alloy is sold on the basis of its molybdenum content, and the usual market is for 55 to 65 percent product containing less than one percent carbon. Higher percentages of molybdenum are sometimes desirable and alloys containing 80 percent have been produced.

Ferrovanadium is added to steel to impart a definite quality to the finished product. Under shock or vibration the ordinary steel crystallizes and eventually breaks. The addition of vanadium to the steel prevents this process of crystallization, and steel so treated is capable of standing heavy shocks and continual vibration.

Commercial ferrovanadium runs about 30 to 40 percent vanadium with less than 0.5 percent carbon and is sold on the basis of its vanadium content. It is used for making automobile parts, gas engine piston rods and cranks, and for members of machinery that must resist continuous vibration.

Vanadium has a great affinity for carbon and unless special precautions are taken the ferrovanadium may have too large a proportion of carbon to permit its satisfactory use in steel manufacture. Silicon rather than carbon, is therefore used as the reducing agent in the manufacture of ferrovanadium in the electric furnace. The product is subsequently refined by further treatment in the furnace to reduce the silicon content in the alloy to less than one percent.

Most of the ferrovanadium of trade is not produced in the electric furnace but is produced by the reduction of iron vanadium oxides with metallic aluminum. This is known as the thermit or Goldschmidt

FIG. 2—TOP VIEW OF FURNACE SHOWN IN FIG. 1

process. The alloy can be produced as cheaply in the electric furnace but the electric process is not as widely used as the thermit process because the thermit process was well established with the largest producers in the country before a suitable electric furnace process was developed.

Ferrotitanium is used to remove oxygen and nitrogen in steel that is to be rolled or cast. Its principal use to date has been in the production of high quality steel rails and in high grade steel castings. Commercial alloy runs 15 to 25 percent titanium. A variation of this alloy is produced directly from a titanic iron ore known as ilmenite, by reduction with carbon in the electric furnace. This is the ferro-carbon titanium of trade and contains 15 to 18 percent titanium with four to six percent carbon. It forms the greatest source of titanium for the steel industry.

Ferro-uranium is used in steel manufacture as a substitute for part of the usual quantity of tungsten in

high-speed steel. It has been found that in place of 17 percent tungsten, eight percent tungsten and one percent uranium can be used without impairing the quality of the steel. This steel is not yet widely used.

The commercial alloy is sold on the basis of its uranium content, which may run from 30 to 60 percent. The production of ferrouranium in the electric furnace is somewhat difficult and the recovery of uranium by a single smelting operation is usually low, due to losses of uranium in the slag. By re-smelting the slag a reasonably high recovery is obtained.

The approximate production of ferro-alloys in the United States during 1918 was as follows*:—

	Gross Tons
Ferromanganese	345 000
Ferrosilicon	100 000
Ferrochrome	30 000
Ferrotitanium	15 000
Ferrotungsten	8 000
Ferrovanadium	5 000
Ferromolybdenum	300
Ferro-uranium	100

TYPES OF FURNACES

The furnaces used for manufacture of ferro-alloys are of three general types:—the Siemens type, a single-phase furnace;—the single-phase series type;—and the three-phase series type. TheSiemens furnace is always single-phase, with one upper vertical carbon electrode and a conducting hearth of carbon or a water-cooled, steel bottom electrode. The furnace proper consists of a round, oval or rectangular shell of brick work or sheet iron, lined with refractory material. Into the big pot or crucible thus formed is placed the charge to be smelted. The electrodes are suspended from above with cable connections and arrangements for raising or lowering. In the side of the furnace near the bottom is a tap hole through which the molten product is withdrawn. This tap hole is sealed with fire clay when not being used to withdraw the molten product.

The series furnace is so called because two or more electrodes are suspended in a crucible similar to that described previously. The bottom has no electrical connection. If the furnace is single phase there are two vertical electrodes connected electrically in series, but if the furnace is three-phase there are three vertical electrodes each connected to a phase. The larger furnaces used in ferro-alloy work are usually of the series type, but for a small furnace the Siemens type is more satisfactory.

The special forms of furnaces used in steel refining, such as the Heroult, Greaves-Etchells, and other tilting types as used in steel foundry and refining work, are not commonly used for smelting, although smelting may be done in most of them. They are, however, more expensive and elaborate than required for smelting processes and are seldom of sufficient capacity to permit smelting operations being conducted on a sufficiently large scale to be profitable commercially.

Smelting furnaces may have either an open top or an enclosing top for the crucible or furnace pot. The use of the enclosing top increases the furnace efficiency under certain conditions by retaining a considerable amount of the heat. It also prevents the escape of gases which in some instances reduces the loss due to dust and volatilization of the rare metal contained in the alloy. The use of an enclosing top on a smelting furnace has, however, disadvantages, in that it makes the furnace more difficult to charge and sometimes introduces complications in the manipulation of the electrodes which must project through the top. Enclosed top furnaces are comparatively rare in ordinary ferro-alloy smelting practice. In addition to the difficulties caused by the top in charging, the troubles encountered should an electrode break off inside the furnace (which is not a rare occurrence) makes the enclosed furnace unpopular for large installations. However, with small furnaces using small electrodes in the manufacture of alloys which require intermittent operation with a set charge and complete removal of the discharge for every run, closed top furnaces are generally used. Alloys requiring such operation are ferrovanadium and ferro-uranium.

In the ordinary smelting furnace, heat for the smelting reaction is produced by both arc and resistance reaction. There is an arc from each electrode to the charge to be melted, and further heat is produced by the passage of the current through the charge to the other electrode. It is seldom possible to differentiate what portion of the heat is due to the arc and what portion due to the resistance, but judging from results of practical operation most of the heat is produced by the arc. Practically all smelting furnaces operate as combined arc and resistance types, the straight arc type, such as the Rennerfelt, being seldom if ever used.

The electrodes for smelting are always either graphite or armorphous carbon. For some alloys, graphite electrodes prove more satisfactory, but as they are difficult to obtain and are expensive, carbon electrodes are used in by far the larger proportion of the installations. Round electrodes and rectangular electrodes are both in use, the type depending upon details of the furnace construction.

Operations within the furnace are controlled by controlling the power input to the furnace. The heating in the furnace is in general proportional to the k.v.a. expended within it and this k.v.a. can be controlled by regulating the current or the voltage, or both. The electrodes may be suspended into the top of the furnace so that they can be moved up and down readily. In this case the power input to the furnace is usually regulated by means of current control, the electrodes being hoisted if the current becomes too great and lowered if the current falls below a predetermined value. If the electrodes are suspended in a fixed position the power supplied to the furnace is usually controlled by varying the voltage supplied to the electrode terminals.

*Figures by Robert M. Keeney, of Denver, Colo.

From the above it will be seen that smelting furnaces can be divided as follows:—

Single-phase or polyphase.
Open top or closed top.
Fixed or movable electrodes.

The selection of the proper combination for the production of the different alloys is guided by the following considerations.

Polyphase furnaces are in general preferable to single-phase furnaces because of conditions surrounding power supply. Most power companies will not assume a large single-phase load, so that the use of a single-phase furnace necessitates the use of three furnaces on a three-phase system to secure balanced power conditions. If one furnace is shut down it causes unbalanced conditions for which the power company usually charges a penalty. Further the operation of three single-phase furnaces involves an expenditure for maintenance and attendance greater than that involved

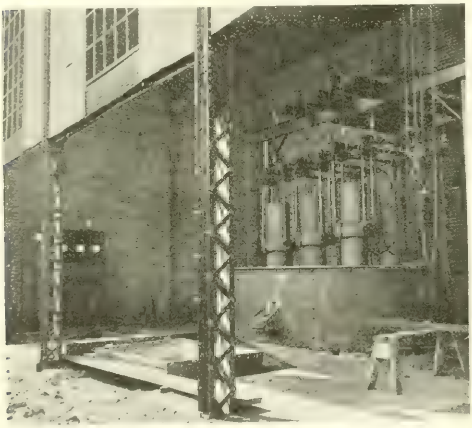


FIG. 3—THREE-PHASE FERRO-ALLOY FURNACE
Fed by three 500 kw. transformers, and equipped with Thury regulator.

for a single three-phase furnace of a capacity equal to the aggregate of the three single-phase units. The first cost of three single-phase furnaces is apt to be slightly greater than that of an equivalent three-phase furnace. Also the single-phase furnaces will require three single-phase transformers, whereas under many conditions three-phase furnaces can be fed from a single three-phase transformer. The switching equipment for the three single-phase furnaces will also cost somewhat more than that for an equivalent polyphase unit.

In the production of certain of the ferro alloys, however, considerations of operation make the use of single-phase furnaces advisable. Such alloys are ferromolybdenum, ferrotungsten, and ferro-uranium.

Ferromolybdenum has a very high melting temperature which increases greatly as the percentage of the molybdenum carried by the alloy is increased. Ferromolybdenum with 50 percent molybdenum will flow at the average temperature maintained in its smelting furnace, and can therefore be tapped from the furnace, but it freezes very quickly. As the percentage of molybdenum is increased to 60 percent or above the alloy has such a high melting point that it cannot be easily tapped. Therefore, in making ferromolybdenum of the 80 percent grade it is necessary to allow the alloy to accumulate in the bottom of the furnace until the proper amount is secured, then shut the furnace down, allow it to cool, pull down the side walls and remove the frozen alloy, which is in the form known as a "button". The walls are then replaced, the furnace recharged, and smelting operations resumed.

Owing to the intermittent operation of such a furnace it is better to conduct operations in a series of single-phase furnaces, only one of which is shut down at a time. The single-phase furnace is also of smaller capacity and somewhat simpler construction than a three-phase furnace, and therefore can be knocked down and re-built more rapidly.

The conditions surrounding the manufacture of ferrotungsten are somewhat similar. Many manufacturers have tried to tap it from the furnace, but the practice has not been altogether successful. Ferrotungsten with 55 to 60 percent tungsten can be tapped, but it is difficult to tap the commercial 70 percent ferrotungsten if the carbon content of the alloy is kept within commercial limits. Furthermore, all of the ferrotungsten in the furnace cannot be tapped, as some of it freezes in the bottom, and it is therefore simpler to let it all freeze and remove it as a button than to remove part by tapping and then have to remove the frozen remainder at a later date. Also the metal poured by tapping is difficult to break up, and therefore it is usually not tapped but handled in a knock-down type of furnace.

Ferro-uranium is usually made in single-phase furnaces because of the high concentration of heat needed in its smelting reaction. On account of the high heat concentration required only small quantities are handled at a time, and these are smelted in a closed top furnace. Under these conditions better results can be obtained with a single-phase furnace than with a larger polyphase furnace. Ferro-uranium with over 60 percent uranium is difficult to tap and is allowed to form a button in the furnace. Lower grades can be and are tapped.

The other ferro-alloys are almost exclusively made in polyphase furnaces. As a rule the larger the furnace, the lower the cost per pound of production. There are, however, certain limits as to the size of furnace that can be economically operated, and these will be discussed under the subject of "Electrical Calculations".

Ferrochrome has been produced successfully on a commercial scale in single-phase furnaces but can be produced to better advantage in larger three-phase units.

Closed top furnaces are the exception rather than the rule. They are used primarily where it is especially desirable to retain a high concentration of heat within

the furnace and sometimes where it is undesirable to allow the fumes generated in the furnace to escape. An example of high heat concentration is that of ferro-uranium mentioned above. It is customary to use open top furnaces where charging of the furnace is more or less continuous. In operations where the furnace is operated intermittently with a set charge, closed top furnaces are used. Alloys made in this way are ferro-uranium and ferrovanadium.

The open top furnaces are used for continuous charging largely because of the ease of operation. Almost all large furnaces are open top on account of difficulties in removing electrodes from a closed top furnace, should an electrode break off in the furnace. The use of a closed top furnace reduces loss from volatilization, but this gain on most of the alloys is just about offset by time lost in removing the roof of a closed top furnace in case of trouble with linings or electrodes.

Most smelting furnaces use movable electrodes. The electrodes are held by a clamp which is suspended by chain or cable from a sheave carried by a structure over the furnace, and the electrodes are raised or lowered by a winch or a chain block, one for each electrode. These winches on small furnaces may be manually operated, but on furnaces of any considerable capacity they are usually electric motor operated. The motor may be either manually controlled or automatically controlled. The electrode is, of course, counterweighted so as to reduce the power required to move it.

Certain operators, however, have a predilection for fixed electrodes, rigidly clamped to a supporting beam above the furnace. This form of construction has some advantages, especially with enclosed top furnaces, which require some form of sealing where the electrodes pass into the furnace. Some operators also claim that better furnace conditions can be secured with fixed electrodes and adjustable voltage control than by means of movable electrodes with adjustable current control.

As stated above the usual form of steel refining furnaces are not used much for smelting work, but some of the larger capacity of Heroult furnaces are being so used, especially in the production of ferromanganese. The particular advantage claimed for a furnace of the Heroult type for smelting work over the ordinary open smelting furnace is that it has greater heat conservation, is easier to tap, and that the furnace reactions can be more carefully controlled.

ELECTRICAL CALCULATIONS

The amount of power required to accomplish any smelting reaction may be calculated theoretically. The weight of the various ingredients for charging the furnace are known and their specific heats are available from chemical handbooks. It is simply necessary to calculate the amount of heat energy necessary in order to bring the mass to the temperature at which the desired chemical reaction will take place, to add the heat energy necessary to initiate the chemical reaction, and deduct from this the amount of heat produced by the combustion which will take place within the furnace of that portion of the charge which is consumed. To this remainder must be added the amount of heat carried away by escaping gasses which can be calculated from the volume of gas which will be produced by the chemical reaction, and also it is necessary to add the amount of heat that is lost by radiation and convection from the sides and top of the furnace. This figure, converted into electrical energy and supplemented by the electrical energy loss due to voltage drop and heating in the leads to the furnace and in the electrodes proper, will give the total number of kilowatt-hours required for a given smelting operation.

These calculations are usually more elaborate than are necessary to determine the capacity of electrical apparatus required for given smelting operations. A more generally useful method is to use figures of kilowatt-hours per ton of alloy produced, based on results obtained in present commercial practice. Such figures are given in Table I.

Manufacturers of the ferro-alloys usually place their problem before the electrical manufacturers with the statement that they require electrical equipment in the shape of transformers and auxiliaries to produce a given quantity of a certain ferro-alloy usually expressed in tons per 24 hours. They will also supply data as to the percentage of time during the 24 hours the furnace may be expected to be operating. For most of the ferro-alloys, especially ferromanganese, ferrosilicon, and ferrochrome, the operation is continuous 24 hours a day, the furnace being supplied with additional charge from time to time, and the melted product being tapped off at stated intervals. There should, therefore, be little interruption of the furnace operation except to renew electrodes. However, with other of the alloys, continuous operation is not feasible as explained above, and in such cases the furnace will only be operating a certain proportion of each 24 hours.

Given the tons or pounds of alloy to be produced, and knowing the kilowatt-hours per pound of alloy required, it is a simple matter, with the time element known, to figure the transformer capacity required to serve a given furnace.

For example, suppose it is desired to determine the transformer capacity to supply a three-phase furnace to produce 150 000 lbs. of 65 percent ferrochrome per month. There would then be required an output of 5000 lbs. per day. If the furnace were kept in operation from 80 to 85 percent of the total time during the month (that is, taking time out for shutdowns due to electrode changing, lining repairs, etc.) 5000 lbs. would have to be produced in about 20 hours. This would mean a production of 250 lbs. of alloy per hour. From Table I the production of 65 percent ferrochrome will require from 3 to 4.5 kw-hrs. per pound of alloy. This furnace is of such size, and the grade of alloy produced sufficiently high, that we may estimate on four kw-hrs.

being required per pound of metal tapped. Therefore 1000 kw-hrs. are necessary to produce 250 lbs. of alloy in an hour, i. e., the electrical equipment must have a capacity of 1000 kilowatts.

The furnace will, however, not operate at 100 percent power-factor—the actual power-factor probably being between 80 and 90 percent. Assuming 80 percent for safety, a transformer capacity of 1200 k.v.a. should be installed to take care of this furnace.

The low-tension voltage of the required transformers can also be determined from the Table I and this varies with different alloys. The quantity "Electrode Voltage" given in the table is the voltage that must be supplied to the furnace, measured at the electrode terminals, and is made up of the arc voltage plus a reasonable allowance for drop in the electrodes. To this must be added, in order to obtain the desired low tension transformer voltage, the calculated resistance and reactance drop in the leads from the transformers to the electrode holders. This, of course, will depend upon the distance between transformers and furnace, upon the size of conductors, upon the amount of interlacing of the leads, and upon the skin effect encountered in the conductors. All of these quantities are susceptible to reasonably accurate electrical calculation. In a well planned installation, where the transformers are placed close to the furnaces, where the conductors are of ample size, properly designed, and thoroughly interlaced, the total drop at full load between transformer terminals and electrodes should be between four and eight percent, most of which will be found to be reactance rather than resistance drop.

As regards the adding of external reactance in the primary supply line to the furnace transformers, modern practice does not seem to favor introducing extra reactance into the circuit, either by means of choke coils or special transformer windings, as sufficient reactance for stablizing furnace operation is secured in the low-tension leads from the transformer to the furnace (in fact it is difficult to eliminate it), and additional reactance elsewhere in the circuit simply reduces the power-factor and probably increases the power charge due to such power-factor reduction. The only electrical advantage of reactance introduced in the transformer or in the primary circuit is the protection of the transformer windings in case of short-circuits in the furnace, and, inasmuch as transformers can be produced to withstand the strains of such short-circuits, it is more desirable to guard against such abnormal conditions by adequate mechanical design of the transformers, than by penalizing the operation with an undesirable characteristic continually in the circuit.

It has been stated previously that in general large furnaces are able to produce most of the ferro-alloys at a cheaper price per pound than small furnaces. This is due to the reduced cost per pound of capacity of the large furnace, of its electrical equipment, and of the labor charge for operating and maintaining it. Power in large quantities can usually be purchased somewhat cheaper than in smaller quantities. The heat losses in large furnaces may also be somewhat reduced from those encountered with smaller installations. There is, however, a limit to the economical size of furnaces, and this limit is fixed by electrical conditions. As can be seen from Table I a certain power imput is required per ton of charge, depending upon the material to be smelted. With designs of the present date there is a rather definite limit to the amount of power that can be introduced into a given furnace due to electrical limitation. There is, of course, no use building a furnace of such size that the necessary kilowatts per ton of charge cannot be supplied to it.

TABLE I—POWER REQUIRED FOR SMELTING FERRO-ALLOYS

Alloy	Grade Product Percent	Size of Furnace: Tons Charged	Size of Furnace: Kilowatts	Type Furnace	Electrode Voltage	Percent Recovery	Kwhrs per lb. Alloy Tapped
Ferrochrome	60-65 Cr. 4-6 C.	13-15	750	3 ph.	120	70-80	3-4.5
Ferromanganese	75-80 Mn.	15	1200	3 ph.	72	70-85	2.2-3.3
Ferromolybdenum	60-65 Mo. 15-2 C.		150	1 ph.	65	78-80	7-7.5*
Ferrotungsten	70-75 W.	0.75	150	1 ph.	95	80-90	2.1 Smltg. 1.7 Refg. 3.8 Total
Ferrovanadium	30-35 V. 3-4 Si.	1	150	3 ph	65	75 Av.	3.4
Ferro-uranium	35-50 V. 3-4 C.	800 lb.	75	1 ph.	35-65	75	3-5
Ferrosilicon	50-70	3-4	1000	1 ph.	60-90		2.5-3

*Per lb. of Mo. in alloy.

The data in Table I was obtained from a number of furnace installations. It should be remembered that the kilowatt-hours per pound for different alloys is affected to a considerable degree by the size of furnace, method of operating, quality of the ore, etc.

The success of any ferro-alloy installation is dependent on many features. Equally as important as the proper design of furnace is the proper selection of electrical equipment. The electrical equipment usually required consists of protective apparatus, furnace transformers, winch motors, furnace control panels, and automatic regulators for the electrodes. Another important feature is the design and layout of the cable or bus beween the furnace and transformers. Particularly, is this true on the larger sized furnaces operating on 60 cycle circuits. Such questions as inductance, reactance, skin effect, etc. must be given full consideration in order to insure getting the proper amount of power and delivering the desired voltage at the furnace.

Electric Brass Melting--Its Progress and Present Importance

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THE electric melting of brass has, until very recently, lagged far behind the use of electric furnaces in the steel industry. Although, for some ten years past, the possible application of the electric furnace for melting brass and other copper alloys has been the object of much experimental work, it was not until about two years ago that the first commercial installations of such furnaces were made. Even these proceeded haltingly and were not an unqualified success. During the past year, however, progress has been very rapid and there can no longer be any doubt but that the electric furnace is destined very soon to become a far more important factor in the brass industry than the electric steel furnace is in its field. Even now, although there are in the United States and Canada some 300 electric steel furnaces as compared with not more than 100 electric brass furnaces, and despite the fact that the average electric steel furnace has a far larger hearth capacity than the average brass furnace, nevertheless it is probably true that the proportion of brass now melted electrically is nearly, if not quite, as great as the corresponding figure for steel.

The reason for the present extraordinarily rapid growth of electric brass melting lies principally in the important saving of metals, especially zinc and lead, which the use of the electric furnace makes possible. The electric process, however, has certain other important advantages over the methods which it is superceding; as discussed in some detail in this article. It is also intended to trace the development of furnace design, and to show how points of weakness have been eliminated and new principles of design utilized in the development of those electric-furnace types which are now, in varying degree, winning commercial success.

THE FIELD OF ELECTRIC BRASS MELTING

In 1914 it was estimated by Gillett* that there were, in the United States, at least 3600 plants engaged to some extent in melting brass and bronze. It was further estimated that the value of the metal annually melted by these plants was in the neighborhood of $120 000 000 and that, of this total, the value of the metal lost beyond recovery during the melting operation was not less than $3 000 000.

During the war, the military uses of brass and bronze expanded these totals enormously and it was this, more than any other factor, which gave the electric process the remarkable impetus which characterized its growth during 1918. Although the annual production of articles manufactured from copper alloys is unquestionably less now than it was during the last year or two of hostilities, it is probably considerably above the figures named by Gillett for 1914. It must be remembered also that all metal prices are higher now than they were then and that this factor increases the magnitude of the metal values dissipated by fuel-fired furnaces. An avoidable waste of metal which was considered important under pre-war conditions, has ever since deserved and received, in constantly increasing measure, the attention of progressive metallurgists.

It has long been known that it is theoretically possible to eliminate much of this loss by the use of electric furnaces, particularly in the case of yellow brass and other alloys containing a high percentage of zinc. Most of the electric-furnace development in the copper-alloy field has been carried out with this end in view. Metallurgically speaking, the problem is not a simple one and for a long time the progress made seemed rather halting. A very considerable degree of success has, however, finally been attained.

Three distinct types of electric furnaces are now available and in commercial use for melting yellow brass, one highly efficient but limited in its use to a portion of the field, a second type less efficient but otherwise more widely applicable and a third almost as efficient as the first and even more flexible than the second in the wide variety of its applications. Two or three additional types are being actively developed and give some promise of eventual success.

Previous to the war the use of electric furnaces for melting copper alloys did not seem feasible except in cases when a large metal saving helped to counterbalance the higher cost of electric heat. Under war conditions, the high cost and poor quality of crucibles, the high cost and shortage of important metals, the high cost and scarcity of labor, and the insistent demand for a high rate of production at any cost, were factors which combined to make electric melting profitable in many cases where it would previously have been unprofitable. Since the armistice, some of these favorable conditions have persisted to a rather unexpected degree and there is no apparent reason to suppose that conditions will ever be materially less favorable to electric melting than they now are. Incidently, all varieties, of fuel have increased in price to a much greater degree than has been the case with electric energy and this factor also appears to be a progressively favorable one.

ADVANTAGES OF ELECTRIC MELTING

Electric heat is expensive at best, and although it can be applied much more efficiently than heat derived from fuel, particularly at high temperatures, it could

*H. W. Gillett: "Brass-Furnace Practice in the United States, *Bureau of Mines Bulletin No.* 73, p. 9 (1914).

[illegible] until very recently, except in cases where its use made possible special savings to offset its added cost. A unit of electric heat still costs far more than a unit of heat from the common fuels but the margin between them has narrowed sufficiently to permit, in many cases, an overall balance in favor of the highly efficient electric furnace as compared with the relatively very inefficient fuel-fired furnace. In the more efficient types of electric brass furnaces, electric energy at one cent per kilowatt-hour is less expensive than coal or coke at ten dollars per ton, or fuel oil at six cents per gallon.

The special advantages which normally result from electric melting, as compared with melting in fuel-fired furnaces are, in general, as follows:—

1—*Metal Saving*—The saving of metal, otherwise unavoidable lost, is the principal economic advantage which the electric furnace is required to show in the melting of copper alloys, particularly in melting yellow brass. It has been demonstrated, both in the laboratory and in the plant, that such a saving is made in the electric furnace, by virtue of the fact that the furnace chamber can be tightly closed during the melting period, and a neutral or reducing atmosphere maintained. As we shall see later on, it does not follow that every electric furnace is capable of a favorable performance in this respect. The electric furnace possesses other important advantages but no electric furnace can hope to achieve real and lasting success in this field unless its use results in a saving of metal as compared with fuel-fired practice.

2—*Improved Quality*—It has been found that a more uniform quality of metal can be produced in the electric furnace than in fuel-fired furnaces operating under similar conditions, and that it is easier to produce an alloy of closely specified composition. The molten metal is also much cleaner and can be poured free from metallic drosses without the use of charcoal or fluxes of any kind. In general, these advantages are to be considered as inherent in properly conducted electric-furnace operation, as a result of the greatly reduced loss of volatile metals and the elimination of contaminating combustion gases.

3—*Exact Temperature Control*—The production of perfect castings or billets, with the least possible number of defectives, depends in a large degree upon the use of metal at a temperature which conforms closely with that known to be most favorable for the work in hand. The electric furnace lends itself readily to exact temperature control and thereby enjoys an important advantage.

4—*Increased Production*—In general, the speed of melting is greater with electric furnaces than with fuel-fired furnaces, because of their higher operating temperature and greater efficiency. The electric furnace can also be used in larger units than is commonly the case with fuel-fired furnaces.

5—*[illegible] Crucible Cost*—The cost of crucibles has always been a considerable item in the brass foundry. While the cost per crucible is now less than it was during the war and the quality of crucibles is somewhat higher than it has been, the cost per ton of metal melted is still much higher than it was five years ago. The electric furnace eliminates this item of expense. Large fuel-fired furnaces effect the same saving but, from a metallurgical point of view, are seldom as satisfactory as fuel-fired crucible furnaces.

6—*Incidental Savings*—The operation of large units results in an economy of floor space and of labor, dependent upon the use of large electric furnaces where large fuel-fired furnaces are not practicable. The labor of handling fuel and ashes is entirely eliminated and in some cases the cost of insurance is reduced.

7—*Better Working Conditions*—More favorable conditions for the workmen, tending to increase their efficiency as well as their comfort, result when excessive heat, noise and fumes are eliminated. The properly chosen and correctly operated electric furnace is almost ideal in this respect. In installations where the reverse is true, the trouble is due to the use of an unsuitable furnace, to careless operation or to both of these as contributing causes.

It should not be understood that these advantages necessarily follow from the use of any electric furnace which may happen to be selected. The furnace must be of suitable type, properly designed and correctly used. A misapplied electric furnace may prove worse in almost every respect than the fuel-fired furnace which it replaces.

REQUIREMENTS OF ELECTRIC MELTING

First consideration must always be given to metallurgical requirements. No electric furnace can achieve success unless it performs satisfactorily the function which is expected of it, no matter how efficient it may be nor how admirable its design may appear to be in other respects. Unless the design is metallurgically correct the furnace is useless as an industrial tool

From a metallurgical standpoint the electric melting of steel is a comparatively simple matter. Steel melts at a high temperature and may be heated as rapidly as desired during the melting operation, providing it is not exposed to contaminating elements during the process. With copper alloys the case is quite otherwise. Copper itself is somewhat volatile and oxidizes much more readily than steel, when in the molten state. Lead is more volatile than copper and oxidizes very easily. Zinc is exceedingly volatile at molten brass temperatures. All copper alloys must be treated carefully during the melting process in order that loss of metal by oxidation and volatilization may be kept low.

Yellow brass for thin castings must be poured at a temperature not far below its boiling point in order that the metal may be sufficiently fluid. At this temperature, zinc, which comprises 30 to 40 percent of the alloy, has a tendency to vaporize rapidly. So long as the metal is contained in a tightly closed furnace chamber, which can easily be done in the electric furnace, this

tendency is counterbalanced by the vapor pressure of the metal which has already been vaporized and with which the furnace atmosphere is saturated. When the furnace is opened for pouring the metal, or for any other purpose, the vapor pressure is released and further quantities of zinc will escape from the alloy without restraint. If the heating has been perfectly uniform and all portions of the melt are at approximately the same temperature, the loss of zinc which ensues will constitute an unavoidable minimum. If the heating has not been uniform, some portions of the melt will be at a temperature higher than the desired pouring temperature, and such portions will lose zinc at a higher rate. If the lack of temperature uniformity is very great the loss which occurs after the furnace is operated and during pouring, will be decidedly excessive. In fact, some portions of the metal may be so seriously overheated during melting that the high vapor pressure generated within the furnace will force considerable quantities of zinc vapor through crevices in the furnace structure. In some cases it may be practically impossible to keep the furnace chamber closed, even to a reasonable degree. Under such conditions the zinc losses are likely to be quite as serious as in fuel-fired crucibles, or even more so.

What is true of yellow brass poured at a temperature near its boiling point is also true, although in less degree, of yellow brass poured at lower temperatures, and of other copper alloys. The lower the percentage of volatile metal the more easily the alloy will stand up under uneven heating. But it can be accepted as an axiom of copper-alloy melting that heat must be applied to the metal as uniformly as possible, whether the alloy under treatment is a brass, a bronze, or some one of the less common alloys. If the application of heat in the furnace lacks uniformity to a serious degree, an excessive loss can only be prevented by some method of stirring the metal, and this stirring must be effected within the furnace, without opening the furnace doors. The metal as poured from the furnace must be uniform in composition, with its various constituent metals thoroughly well mixed and alloyed. In some cases a rigidly specified composition must be closely met. The finished casting, ingot, or billet must be of a quality at least as good, with respect to strength, freedom from cracks, blowholes, etc., as that obtainable from fuel-fired crucible furnaces.

Since electric heat is more costly than that derived directly from fuel, it is important that the thermal efficiency of the electric furnace should be as high as can be obtained consistent with other requirements. A high thermal efficiency in electric melting, unless the heat is generated in the metal itself, requires a high-temperature heat source, located as close as may be to the metal, under conditions which offer the least possible opposition to the flow of heat from the source to the metal. In addition, the walls of the furnace must be sufficiently thick and of high heat-insulating quality in order that heat may not be dissipated uselessly.

In some furnace types these requirements are directly opposed to the metallurgical requirements already considered. In such cases thermal efficiency must be sacrificed to as great a degree as may be necessary in order to satisfy the metallurgical requirements. The highest efficiency compatible with good metallurgical results should be maintained; any higher efficiency is false economy. It is, however, obvious that, other things being equal, the more efficient type of furnace will meet with greater success.

The electric furnace, to reap the full benefit of its economic possibilities, must operate in large units and must not use crucibles. The higher its speed of melting the better, so long as speed is not detrimental to metallurgical results.

The electrical characteristics of the furnace must be such as to make it a desirable load for the central-station company or the factory power plant. Its power-factor must not be abnormally low and its power fluctuations must not be so violent as to endanger transformers and other electrical equipment, or to interfere with satisfactory service to other customers of the central-station company who may be connected to the same power line.

In order to be thoroughly satisfactory the electric brass-melting furnace should be highly flexible. That is to say, it should be able to operate under any desired foundry conditions, and to handle a charge of any ordinary nature and composition. The furnace should be readily applicable to any schedule: one-shift, two-shift, or three-shift daily operation. The melting of new metal, or composition ingot, or coarse scrap, or fine scrap, or a charge with a high non-metallic content, should all be practicable in the same furnace, and it should be possible to change from one composition to an entirely different one, in successive heats, without affecting adversely the operation of the furnace or the quality of metal produced. With reference to these features the electric furnace must at least equal the performance of fuel-fired furnaces. As a matter of fact, the electric furnace can be made more flexible than other furnaces, and thereby gains a material advantage.

It seems hardly necessary to add that the successful electric furnace must be sturdy and reliable, quite as capable of performing its function, day in and day out, under regular operating conditions, as are the best types of combustion furnaces. The furnace and its adjustments should be as simple as possible, although with a large electric furnace it is permissible, and nearly always advisable, to use a higher grade of operator than would be employed to tend fuel-fired furnaces.

FURNACE DEVELOPMENT

With these requirements more or less perfectly in view, a great variety of electric furnace types have been proposed and tried out for melting brass. It is hardly an exaggeration to say that every known method of applying electric heat to a metal has been utilized by one or another of various designs which have reached at least an advanced experimental stage. Some

of these types have been eliminated as inherently unsuited for the purpose; some have been abandoned because of difficulties which may eventually be overcome by other investigators; others, partially successful, have apparently reached the height of their development; still others seem to possess greater possibilities of ultimate success than have yet been demonstrated.

DIRECT-RESISTANCE FURNACES

The most obvious method of reaching a high thermal efficiency without overheating the alloy is to generate heat in the metal itself by the passage of an electric current through it. This may be done by means of a direct resistance furnace, in which electrical contact with the metal is made through electrodes, or by an induction furnace, in which case the metal forms a complete circuit for the flow of an induced electric current, without the use of electrodes. In either case it is practically necessary to establish the circuit, initially, through molten metal previously melted in some other furnace.

THE PINCH-EFFECT FURNACE

The "pinch-effect" direct-resistance furnace was the first to utilize this principle. In this type the electric circuit consists of two or more vertical or inclined resistor channels in the hearth of the furnace, terminated at the lower end by electrodes, and opening at the upper end into the main body of the metal bath, which conducts the electric current from one resistor channel to another. The resistor channels are so designed as to length and cross-section that the pinch phenomenon occurs in them continuously during operation. The resultant effect is a constant stream of hot metal issuing from the resistor channels, with considerable force, into the bath above, while colder metal flows down to take its place and is heated and ejected in its turn. Virtually all of the heat is generated in the molten metal temporarily occupying these channels or tubes. The main portion of the metal, occupying the furnace chamber above, is heated by contact with the hot metal, while solid metal added to the bath is melted by the same means.

The stirring action of the moving streams of metal is vigorous and the temperature of the bath rises uniformly. There is no difficulty in restraining the vaporization of zinc, and the metallurgical requirements of any single alloy are almost perfectly fulfilled.

Generation of heat in the metal itself is theoretically ideal from the standpoint of efficiency, since no part of the furnace is any hotter than the metal, and wall losses are reduced to a minimum. In this case, however, another factor tends to reduce the efficiency. The operating voltage of the furnace is necessarily very low and the current correspondingly high. The massive metallic electrodes are excellent conductors of heat and require a considerable degree of water cooling. In this way a large quantity of heat escapes from the furnace, and the thermal efficiency is much lower than would otherwise be the case.

Considerable difficulty has also been experienced in constructing satisfactory transformers for use with such extremely low voltages and high currents.

THE INDUCTION FURNACE

The next step in this development was the application of a similar principle to the induction furnace. This eliminated the use of electrodes and the troublesome transformers, since the furnace now served as its own transformer. In this design the resistor channels meet at their lower end, two of them forming a single V-shaped resistor, opening as before into the bath above. Again the generation of heat takes place in the resistor channels and the same vigorous circulation of metal results. Whether this circulation is now due primarily to the pinch phenomenon, or to a motor effect resulting from the flow of current through the continuous molten resistor, is open to question. It is difficult to tell where one phenomenon stops and the other begins.

The thermal efficiency of this furnace, operating, as it does, without electrodes, is very high, probably higher than that of any other electric furnace of similar size ever tried out for copper alloy work. Its metallurgical characteristics are also excellent. It offers a perfectly steady, uniform load at a power-factor which is satisfactory, at least in the relatively small sizes so far built, the largest taking a 60 kw. input and pouring 600 lbs. of metal per heat. In larger sizes there would probably be trouble with low power-factor, as is so frequently the case with large induction furnaces.

The induction furnace is in commercial use and is said to be giving satisfactory results. It has, however, pronounced limitations which are partly inherent in its design and partly remediable. Its small size is one disadvantage which can perhaps be overcome to some extent. It has not so far been found practicable to use the furnace with alloys high in lead, because that metal has a tendency to penetrate minute cracks in the lining of the resistor channels, causing short circuits and disruption of the lining. The remedy for this awaits the development of a lining suited for use with lead.

The more serious limitations of the furnace are its lack of flexibility in changing from one alloy to another and the practical necessity of operating it continuously, allowing the furnace to cool not oftener than once a week. The length and cross-section of the resistor channels are especially designed to correspond with the electrical resistance—in the molten state—of the alloy which is to be used. The same resistor channels cannot be employed with another alloy of widely different resistance, which, accordingly, requires the installation of new channels of properly modified design. In changing from one alloy to another, even if the resistance is approximately the same, it is necessary to pour the furnace clean and start with a molten charge of the new alloy, melted in another furnace.

The linings of the resistor channels stand up very well under continuous use but deteriorate rapidly under the daily heating and cooling of eight or ten-hour daily operation. This can be obviated by maintaining over

night sufficient power to keep the channels filled with molten metal, which, of course, results in some addition to the cost of operation.

The limitations described tend to prevent the use of this furnace in commercial foundries, which melt a wide variety of alloys and do not work nights, but are not so objectionable in rolling mills, to the purposes of which it seems fairly well suited. Even in the rolling mill, however, the furnace is considerably handicapped by its small capacity and its use has not developed greatly during the past year.

AN INDIRECT INDUCTION FURNACE

About two years ago there was proposed a new design of induction furnace which would not be subject to these limitations. In this type a spark gap and an arrangement of condensers connected in series and in parallel are used in the primary circuit of the furnace, which operates at about 10 000 volts and some 15 000 to 20 000 cycles. A high-frequency alternator may be used, in place of the spark gap and condensers, to produce the same conditions. The secondary of the furnace consists of a crucible or melting chamber with electrically conducting walls; the metal within the crucible also carries part of the secondary current, to a minor degree when it is first charged in the solid form, to a much greater degree when it becomes molten. The primary circuit is arranged around the melting chamber and separated from it by suitable refractory and heat insulating walls. The furnace is, in a sense, an eddy-current furnace rather than an induction furnace, since no iron cores are used and the metal, lying in a circular pool, completely short circuits what, in an induction furnace of the usual type, would be called the secondary circuit. This unique arrangement is made possible by the exceedingly high frequency used.

This furnace has only been built in very small sizes, capable of pouring not more than 45 lbs. of metal per heat. It has been used primarily for laboratory purposes and for the preparation of carbon-free alloys of some of the rare and more refractory metals. Up to the present time no serious attempt has been made to market it as a brass-melting furnace and it requires much development before this could be done.

The design of the furnace is so new and unusual that it is difficult to predict the performance of larger sizes, as to efficiency, power-factor, etc. There is no apparent reason why the metallurgical characteristics should not be good, and the construction of the metal-containing portion of the furnace is desirably simple. On the other hand, the electrical primary of the furnace is expensive, cumbersome and complicated, requiring special construction entirely out of the range of ordinary electrical equipment. It is obviously unnecessary to use molten metal in starting the furnace. Any alloy or even non-conducting material, such as glass, can be melted without changing the furnace design. The furnace is suitable for intermittent operation and need not be kept hot over night.

DIRECT-ARC FURNACES

The application of direct-arc furnaces to copper-alloy melting has been rather limited. One or two furnaces designed for steel melting have been tried, but no new type of direct-arc furnace has been developed for this specific purpose. No furnace of this general type has ever succeeded in satisfactorily melting yellow brass, or other copper alloys containing an appreciable percentage of zinc. The high-temperature heat source in direct contact with the bath overheats the metal and invariably causes an excessive loss of zinc.

With copper alloys containing no zinc the case is somewhat different, since lack of uniformity in heating is less likely to result in serious loss. In a direct-arc furnace of small size it has been found possible to melt a copper alloy containing as much as 15 to 20 percent of lead at a loss less than that commonly experienced with the same alloy in fuel-fired crucible furnaces. In larger furnaces the results were not so good, since the greatly increased rate of heat input supplied heat to the metal, in the neighborhood of the arc, more rapidly than it could be conducted away to more distant portions. In this way the surface of the metal becomes overheated while other parts of the bath are still much below the desired temperature.

The direct-arc furnace has the advantage of simplicity and high thermal efficiency; its design has been more highly developed and perfected than that of most other electric-furnace types, and, since it is so widely used in the steel industry, several furnace designs are on the market, reliable and readily available. It is very doubtful, however, if any direct-arc furnace deserves wide application for melting copper alloys. Its use is limited to only a few of the common alloys, and, if large units are employed, the metal loss, even with these alloys, is likely to be serious.

During the war at least one direct-arc furnace installation held its place by virtue of its simplicity, elimination of crucible cost, and its high rate of production, at a time when these qualities were at a premium. Even in this installation the continued use of direct-arc furnaces is highly problematical, while new installations, of a similar character, are not likely to be made.

INDIRECT-ARC FURNACES

The intensity of heat application to the metal is lessened somewhat by using an arc between two or more independent electrodes above the bath, heating the latter by direct radiation. This is the principle of the usual type of indirect-arc furnace. The arc does not come in direct contact with the metal and the latter forms no part of the electric circuit. It is apparent that in this type of furnace the surface of the metal is not so seriously overheated as in the direct-arc furnace but such overheating as does take place is, nevertheless, too severe to permit the use of these furnaces in melting yellow brass. The indirect-arc furnace can be used economically with alloys containing 5 to 10 percent of zinc. Several of these furnaces are now in

use in this country for melting copper alloys containing small percentages of zinc.

THE ROCKING INDIRECT-ARC FURNACE

In a new type of indirect-arc furnace, placed on the market about a year ago and widely adopted since that time, the metal, as soon as it becomes molten, is agitated by rocking the furnace mechanically, in order to avoid overheating of the surface layer. In this way surface overheating is eliminated and all parts of the bath are heated with remarkable uniformity. All grades of copper alloys, including yellow brass, have been successfully melted in this furnace, the loss of zinc and other volatile metals having been reduced almost to the vanishing point.

The efficiency of this type of furnace is very high, much higher than that of the stationary indirect-arc furnace, somewhat higher than that of the direct-arc furnace; in fact, it is practically on a par with the induction furnace in this respect. The increased efficiency of the rocking indirect-arc furnace is due to heat reclaimed from the walls of the furnace, a sort of regenerative process. In any stationary arc furnace all parts of the furnace chamber which are located above the metal line are superheated by the arc to a temperature considerably above that of the metal, and the radiation losses from furnace roof and walls are large. In the rocking furnace about four-fifths of the area of brick exposed to direct radiation from the arc is washed twice each minute by the cooler metal, which absorbs the excess heat in the brickwork and thus increases the percentage of heat usefully applied.

The vigorous mixing which the metal in the furnace undergoes results not only in uniformity of temperature but also in uniformity of composition. This is a particularly important feature in the melting of alloys high in lead, which are notoriously difficult to produce in homogeneous mixtures. Unfortunately these alloys, as already mentioned, cannot be handled in the induction furnace, which would otherwise be remarkably suitable for the purpose because of its vigorous mixing action. In the rocking arc furnace, however, alloys containing as much as 25 percent of lead have been poured into homogeneous ingot and castings without any mechanical stirring other than that offered by the furnace itself.

The success of this type of furnace has been due primarily to the fact that it combines the high efficiency and rapid melting of the arc furnace with the high quality of metallurgical performance previously obtained only in the laboratory or in less efficient types of furnace. It has also been found capable of handling lower grades of scrap than have commonly been melted in any furnace except the reverberatory. In the rocking furnace the melting of brass and other copper alloys has been placed on nearly as simple a basis as that which has made the electric melting of steel so successful.

There has recently been proposed a modification of the rocking indirect-arc furnace, in which the furnace body is continuously rotated instead of being rocked backward and forward through a limited arc. This new design is apparently based on the assumption that if partial rotation is good, complete rotation would be better. This conclusion, however, overlooks the importance of several features which have played a prominent part in the success of the rocking furnace.

In the first place, although rocking of the furnace is unnecessary during the first few minutes of the heat, while the metal is still entirely solid, it is necessary to begin the mixing process before all of the metal is melted, since otherwise an excessive volatilization of zinc will begin at this point. The initial rock, begun at this time, must be moderate in degree or pieces of solid metal will fall against the electrodes and break them. This initial rock is gradually increased until, when the charge is entirely molten, the full rock is employed. In this way the degree of agitation is always suited to the condition of the charge and metal losses are avoided without endangering the electrodes. If, at the temperature where zinc begins to volatilize in quantity, the furnace were to be completely rotated, breakage of electrodes by unmelted portions of the charge could not be avoided, unless indeed the charge consisted entirely of borings and very thin scrap, of such light weight that the electrodes could receive its impact with impunity. If, on the other hand, agitation of the metal is deferred until the furnace can be completely rotated without danger to the electrodes, surface overheating, accompanied by serious metal losses, cannot be avoided.

Complete rotation of the furnace also complicates the electrical and mechanical design to an undesirable degree. Since the electrodes must rotate with the furnace, it is necessary to conduct the electric current from the bus terminals to the electrodes through shoes which make contact with copper slip rings on the furnace shell, somewhat similar to the contact employed between the third rail and shoe in the third-rail system of electric traction. While this can be done with fair success so long as the electric current is relatively small, it is well nigh out of the question for the heavy currents required by large electric furnaces. With complete rotation of the furnace it is also necessary to carry the cooling water, required by the electrode holders, through a sort of revolving universal joint.

There seems no reason to suppose that complete rotation of the furnace will improve the metallurgical or electrical performance in any way, while it certainly conflicts seriously with the requirement that the electrical and mechanical design of any electric furnace must be as simple as it can be made, in order to avoid interruptions in operation and high maintenance cost. It is also to be doubted whether complete rotation of the furnace is so conducive to thorough mixing of the metal as is the rapid reversal of rotation employed by the rocking furnace.

INDIRECT-RESISTANCE FURNACES

Resistance furnaces which do not utilize the metal

itself as an electric resistor may be grouped in three classes:—(1) Those which radiate heat directly to the metal, similar in principle to the stationary indirect-arc furnace; (2) those which radiate heat to the furnace roof and thence to the metal by reflection and secondary radiation; and (3) those which feed heat to the metal by conduction through a refractory wall.

Heating by direct radiation is the most desirable of the three from the standpoint of efficiency. For this purpose it is practically necessary to support the resistor above the bath in some manner, and this has never been done successfully in furnaces of any considerable size. In small furnaces it has been possible to utilize this principle and to melt brass satisfactorily without overheating the surface of the metal to an undesirable degree, since, as compared with an arc, the resistor has a large area and operates at a much lower temperature. At the same melting speed the application of heat to the metal is more uniform but the efficiency is less.

This type of furnace is applicable to yellow brass but is not in commercial use because of the mechanical difficulties involved in its construction. The possibility of its eventual use depends upon the development of a resistor material which is at once highly refractory, homogeneous, mechanically strong at high temperatures, and possessed of a fairly high electrical resistance at the working temperature of the furnace.

The second type named ranks next in the order of thermal efficiency. In this design a refractory wall separates the resistor from the metal—although not necessarily in contact with the metal—and the major portion of the heat is radiated from the resistor to the furnace roof, the latter acting as a secondary heat source which reflects and radiates part of the heat which it receives to the bath beneath it. The heat has to travel rather a long path and much of it is lost by the wayside. As a result, the furnace is not so efficient in principle as those previously discussed. In order to stimulate a reasonably rapid flow of heat the resistor element must be much hotter than the roof, and the roof, in turn, much hotter than the metal. Thus the possibility of a rapid rate of melting depends upon the use of a resistor capable of operating at a temperature very much above that of the metal, even at its pouring point. The furnace roof must be exceedingly refractory and the brickwork in the immediate neighborhood of the resistor must be even more refractory than the roof. In the present state of the art these conditions are difficult to meet, and the melting speed of this type of furnace is consequently somewhat limited.

The furnace, in common with other indirect-resistance furnaces, contends with another disadvantage, somewhat minor in character but worth considering, which is not found in direct-resistance furnaces nor, to any great degree, in arc furnaces. The heat storage of the furnace is large and the stored heat is at a temperature higher than that of the metal. As a consequence the temperature of the metal will continue to increase after power has been shut off. When the metal has reached its desired pouring temperature it must be poured promptly in order to avoid overheating. It is often impossible to hold the molten charge in the furnace, even for a few minutes, without serious loss.

This is the only form of indirect-resistance furnace which has found commercial use for melting copper alloys. In its present form, it is simple, fairly reliable, easy to operate, and can be used on practically any alloy, for either intermittent or continuous operation. On intermittent operation, however, it should be kept hot overnight because of the sluggishness which otherwise would greatly retard its production during an eight or ten-hour day. So far as the saving of metal is concerned, its metallurgical characteristics are excellent. It does not, however, possess the metal-mixing characteristic which is such an important feature of both the induction and rocking arc furnaces, and it does not operate particularly well on borings or other low grades of scrap. It is more suitable for use with clean yellow scrap than for any other character of charge. Its rate of melting is not rapid and it is much less efficient than any furnace previously described.

A similar type of furnace utilizes a combination of arcs and resistance elements, all radiating heat to the furnace roof, which, as in the furnace just described, serves as a secondary heat source. The use of arcs makes possible a considerably higher power input than in the furnace last described, more rapid melting, and probably a slightly more favorable efficiency, provided a sufficiently refractory roof is used. A very high efficiency cannot, however, be expected from this type of furnace. Although the furnace has been under development for two years, and is now nominally on the market, serious difficulties in design have been encountered which have so far postponed any extensive use of this type.

The least efficient method of transferring heat from its source to the metal is to force it through a refractory wall, even though this wall be that of a clay-graphite crucible, a mixture which has a fairly high heat conductivity. Theoretically, the least undesirable arrangement under these conditions is to enclose the resistor in the refractory wall, or to use the wall itself as a resistor. In the latter case the wall must be separated from the metal by an insulating layer to prevent short-circuiting of the electric current through the bath. It is not an easy matter to make this insulation permanent and this factor has been a serious source of difficulty. A resistor enclosed in a refractory wall tends to reach excessively high internal temperatures, and no material has yet been found, satisfactory in other respects, which will not destroy itself under these conditions. Another troublesome difficulty results from the ease with which most resistor materials unite chemically with the furnace refractories at high temperatures, thereby destroying both themselves and the refractories. Some two or three furnace types designed to make use of this principle have been uniformly unsuccessful.

ELECTRIC CRUCIBLE FURNACES

Finally, it is possible to melt brass in a crucible by means of resistor elements which surround but do not touch the crucible. Perhaps the most perfect results, from a metallurgical standpoint, can be obtained in this manner, but thermal efficiency is at a minimum, and, in any case, the electric crucible furnace lacks most of the secondary advantages upon which the electric brass melting furnace must depend in part for its successful use. It is possible that, in cases where perfection of metallurgical results is by far the most important consideration, an electric crucible furnace can profitably be employed, but, so far as is known to the writer, no commercial installation of this kind exists.

In thermal efficiency the crucible furnace takes its place at the bottom of the list. Its energy consumption per ton of metal produced is about three times that of the induction or rocking arc furnaces. One or two attempts have been made to improve the efficiency by constructing a multiple-crucible furnace, with resistor elements suitably arranged between crucibles. In this way it is possible to make a substantial gain in efficiency, but there are serious objections to this type of construction and its development never progressed very far.

PRESENT STATUS OF ELECTRIC MELTING

To sum up, then, we find that there are five types of electric furnace in commercial use for melting copper alloys. Of these, two types, the direct-arc and stationary indirect-arc furnaces, are really steel-melting furnaces temporarily adopted for brass-melting purposes because at the time of their adoption, nothing better was available. The direct-arc furnace is used for this purpose in only one commercial installation; its limitations and disadvantages are so serious that its further use is not to be expected. The stationary indirect-arc furnace is somewhat more widely used, but, while somewhat better than the direct-arc furnace, it is not particularly well suited for the purpose. Its use is limited to only a few of the copper alloys in common use.

The remaining three types were especially designed for brass melting and, from the metallurgical viewpoint, all three are far superior to either the direct-arc or the stationary indirect-arc furnace. The induction furnace is highly efficient but seriously limited in its application. For continuous operation on yellow brass of constant composition its small size is its only weighty disadvantage. The requirement that it must be operated continuously and without change of alloy limits its use to certain highly specialized divisions of rolling-mill and smelting work. The rocking indirect-arc furnace is nearly if not quite as efficient as the induction furnace, can be built in much larger sizes, and shows a performance throughout the field of copper-alloy melting quite as favorable as that of the induction furnace in its more circumscribed province. It is equally suitable for intermittent or continuous operation and will handle any desired variety of alloys. The indirect-resistance furnace is much more flexible in its use than the induction furnace, somewhat less flexible than the rocking indirect-arc furnace, and far less efficient than either. Its low efficiency and slowness of melting are its principal handicaps.

Thorough mixing of the metal during the melting operation is a new and important advantage which the electric furnace has introduced in the brass industry. The uniformity of metal composition and structure, as well as the even temperature of the metal, which this mixing produces, is often of incalculable benefit. In a sense, it results in a quality superiority for electric brass comparable to the well known superior quality of electric steel. This feature is found only in the induction and rocking indirect-arc furnaces.

PROSPECTS FOR THE IMMEDIATE FUTURE

The introduction of any radically new features in the design of electric furnaces for melting brass does not seem likely. The field has been pretty well thrashed over and the designs at present in use have developed logically, through years of experiment and trial, from a large number of unsuccessful or only partially successful attempts to build an electric furnace really adapted for the melting of copper alloys. There will, of course, be improvement in mechanical and electrical features.

The use of electric brass furnaces is still rather new to the industry and great improvement is to be expected in the methods of their use. Very few furnace installations are showing the maximum performance of which they are capable. This is, of course, no more than natural, since electric melting differs in many important respects from the older methods and it takes time to induce the corresponding charges in the human equation of the foundry. Other important developments are likely to come from the adoption of new and improved foundry equipment especially designed to take advantage of the possibilities which electric melting present.

It is estimated on reliable authority that about one percent of the brass melting in the United States is now done electrically and that approximately 90 percent could profitably be done in this manner. The introduction of electric brass furnaces is at present proceeding very rapidly, more rapidly than was ever the case with electric steel furnaces. Brass rolling-mills, in particular, are adopting the electric furnace and laying plans for its more extensive use. It seems probable that electric melting equipment will be standard in all rolling mills within a year or two. One rolling-mill is advertising electric brass as the greatest advance in that industry during the past 140 years and claims to melt its entire output in that manner. Foundries and smelting plants are moving more slowly but none the less surely toward the same end.

The brass industry is essentially conservative and it will probably be some time before the entire 90 percent adopts electric melting but a period of five years from the present is likely to see 75 percent of this country's output of brass melted electrically.

Induction Motor Drive for Skip Hoists

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CONSIDERABLE interest has been shown recently in the use of alternating-current motors for skip hoist service—a field that has been covered almost exclusively by direct-current equipment. In general, the requirements of the service, as far as the electrical equipment is concerned, are as follows:—

High starting torque—The motor must be able to start under maximum load conditions each time a hoist is made.

Positive slow down and accurate stop—When pulling over the knuckle at the top of the track, and into the dumping position, a slow speed is necessary and the speed, as well as the point at which the stop is made, should be the same under all conditions of load.

Continuity of service—This point applies particularly to blast furnace hoists, which are in service continuously 24 hours a day, 365 days in the year, and for periods as high as eight years at a stretch.

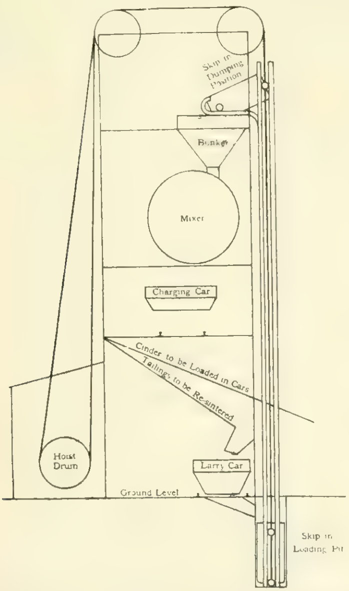


FIG. 1—SCHEMATIC CROSS-SECTION THROUGH THE CENTER OF THE SINTERING PLANT

Showing the relative positions of the equipment and the manner in which the material is handled.

Safety—Provisions must be made to insure against overspeed, over-travel and slack cable.

The above requirements are met in a very satisfactory manner by an alternating-current induction motor having a two-speed winding. In fact, a motor of this type gives better operation on slow speed than does a direct-current machine, since the speed is more uniform under varying loads.

A hoist driven by a motor of this type has recently been put into operation at the sintering plant of one of the larger steel companies. This sintering plant was constructed for the purpose of reclaiming the flue dust from their blast furnaces and converting it into a product from which the iron can be recovered.

Gas, as it comes from the blast furnaces, is heavily laden with a fine brown dust which must be removed before the gas can be used. This is done by dust catchers located at intervals along the flue leading from the furnaces. This dust is comparatively rich in iron, but cannot be charged back into the furnace in its finely divided condition since it would simply be carried out again by the blast. However, if it is converted into some form not so susceptible to strong air currents, a certain percentage of it can be re-charged into the furnace and the iron re-claimed. This is the purpose of the sintering operation.

The flue dust is hauled from the furnaces to the sintering plant, where it is screened and enough water mixed with it to facilitate handling. It is then put into bunkers. A larry car conveys it from the various bunkers to the hoist bucket. It is hoisted to the top of the building and dumped into another bunker, from which it is discharged by gravity down through the mixer into the charging car. The charging car runs astride a stationary grate arrangement called a pan, and as it travels over this pan, it deposits on it a layer of damp flue dust. The charging car is followed by the ignition car which ignites the coke in the flue dust. A down draft through the pan promotes combustion. When the process is completed the resulting cinder is hauled back to the blast furnaces.

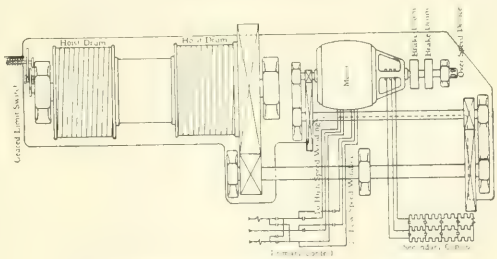


FIG. 2—GENERAL ARRANGEMENT OF THE HOIST PARTS

With a schematic diagram of the main circuits.

The hoist used to elevate the flue dust to the upper bunkers is a vertical, double-balanced skip, the height being 105 feet to the knuckle and 111 feet to the dead point. Each bucket weighs 9000 lbs. and carries a net load of 24 000 lbs. of flue dust. It is driven by a 125-40 horse-power, three-phase, 25 cycle, 220 volt, two-speed wound rotor motor, wound for 6 and 18 poles. The full-load speed on the high-speed winding is 480 r.p.m.

and on the low speed winding 160 r.p.m. The comparatively low ratio between high and low speed—3 to 1—is due to the fact that the maximum rope speed is low. The double drums are six feet in diameter and are driven through a triple gear reduction at a speed of 5.3 r.p.m. high and 1.77 r.p.m. low. This gives a rope speed of 100 feet per minute when running on the six pole winding and 33.3 feet per minute when running on the 18 pole winding.

The operation of the hoist is controlled by a forward and reverse master switch in the operator's pulpit, and a sequence and limit switch geared to the end of the drum shaft. On the contactor panel are mounted the directional switches, pole changing switches for the primary winding, accelerating switches, and overload and no-voltage relays. No pole changing switches are used in the secondary circuit. Although separate windings are used on the rotor for the two speeds, the motor is so designed that when operating at the 18 pole speed the six pole rotor winding has no effect and vice versa.

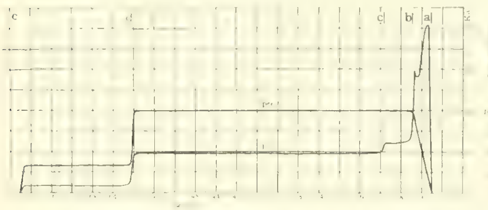


FIG. 3—GRAPHIC RECORD OF LOAD AND SPEED
When hoisting a full bucket.

A shunt brake is mounted on the motor shaft. This brake is set by springs and released by a magnet connected across the motor leads so that the brake is set whenever power is off the motor. A slack cable switch, safety switch and overspeed device are provided, the operation of any one of which will open the control circuit and apply the brakes.

When the operator moves the master switch to the "forward" or "reverse" position, the proper directional switch closes, the brake is released and the motor accelerates on the high-speed winding. When the bucket reaches the knuckle at the top of the track, the geared limit switch opens one contact and closes another, which transfers the power from the 6 pole winding to the 18 pole winding, and the rope speed slows down to 33 feet per minute. When the dumping position is reached, another contact on the limit switch opens the control circuit, cutting the motor off the line and applying the brake. If any of the safety devices operate and stop the hoist, it is necessary to return the master switch to the "off" position before another start can be made.

Graphic meter charts, showing the load and speed conditions on this hoist, are shown in Fig. 3 which indicate the power input and speed when hoisting a full bucket. Section *a* to *b* is the accelerating peak. This is an initial installation and a motor with a very high maximum torque was applied. Over the section *b* to *c* the motor is running at full speed, but the empty bucket which is at the top and being lowered, has not descended over the knuckle and all of its weight is not effective in balancing the ascending skip. At *c* the descending bucket rounds the knuckle and from here to *d* both skips are on the vertical portion of the track. At *d* the slow-down feature operates, the rope speed being reduced from 100 feet per minute to 33 feet per minute. This occurs just as the ascending skip starts to go over the knuckle. From *d* to *e* the ascending load is pulling up in the dumping position, a large amount of its effective weight being removed. This causes the load over this portion of the curve to be very light. At *e* the limit switch opens the control circuit and the brake is applied, bringing the hoist to rest with the upper bucket in the dumping position and the lower one in the pit ready for loading.

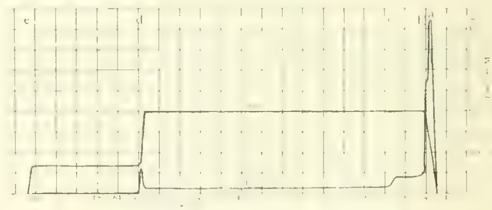


FIG. 4—GRAPHIC RECORD OF LOAD AND SPEED
With both buckets empty.

In Fig. 4, which is similar to Fig. 3 except that both buckets were empty during the hoist, acceleration is appreciably faster but the speed, both before and after slow down, is the same as under the heavy load. At the point of change-over, a short peak is recorded. For an instant after the power is transferred to the low-speed winding, the motor runs above synchronous speed as an induction generator. This continues only until the speed has been reduced to the 18 pole speed. This peak is not experienced when running with the bucket full, on account of the much larger positive load which reduces the speed immediately upon changing windings. The no-load power curve shows that after the ascending bucket pulls over the knuckle, the descending bucket on the vertical part of the track overbalances the system exactly enough to overcome the friction, no power being required by the motor.

Preparation of Technical Papers

B. G. Lamme

THE preparation of a technical paper requires most careful consideration in many ways. Certain fundamental points should be kept in mind at all times, without which the value of the paper may be lessened. The writer has had a certain amount of experience, both in editing and in writing such papers, and the following is a list of suggestions which have occurred to him, from time to time, which may be of some assistance to others:—

MATERIAL AVAILABLE

One should not attempt to prepare a technical article on any given subject, unless he has sufficient good material available to do so. If he has only a small amount of suitable matter, then the article should be correspondingly brief. A little good material should not be "diluted" to form a long paper. Putting more water in coffee doesn't make more coffee—it simply weakens it. To state the matter in another way, a paucity of ideas or data should not be padded out to give a false appearance.

KNOWLEDGE OF SUBJECT

One must clearly understand the subject which he is discussing. It may be assumed that a person cannot explain any matter very clearly if his own understanding of it is indefinite. We reason in more or less definite language and therefore should be able so to express our thoughts. However, we sometimes perceive things in a different language from that used in writing. For instance, our conception of a certain matter may be largely a graphical or visual one and we may picture to ourselves, or visualize, the matter when we think of it. The difficulty of explaining in writing, or the usual language, may thus be one of translation from one form of perception to another. To illustrate, one may recall a picture or drawing, a landscape or a face, and may *see* it perfectly, but cannot describe it in words.

Abstract ideas or thoughts are, however, almost entirely in the form of language, and a measure of one's true knowledge of a given subject is often found in the clearness with which he can express himself.

Frequently, a person can explain himself clearly in oral language, but not in writing. This may be on account of lack of practice, thus necessitating more time in building up word structures, etc.

PREPARING THE OUTLINE

Assuming that one has sufficient material available, it should be classified and arranged in proper logical order or sequence. This may be done by arranging a skeleton outline, comprising the principal parts. A general classification of the subjects and materials may be made first and then re-arranged in proper order.

After such a skeleton is prepared and properly arranged, then each sub-subject, or item, can be expanded by classifying the secondary related material which is to be included. Or, if one is not yet prepared to do this, then each subject can be taken up individually, and its possibilities and related ideas may be worked out. In fact, after the skeleton is once prepared, then each part can be treated to a certain extent as a subject in itself, proper regard being given to its relation to the other subjects.

After the principal elements of the skeleton outline have been arranged in logical order, then the article, as a whole, is ready for consideration. In fact, with the preparation of the outline and its subsidiary parts, the paper may be said to have progressed quite far. The data and facts having been arranged in logical order, it is only necessary to take each one in turn and put down what has been planned to be covered by it. In fact, in many cases, one already knows just about what he wants to say concerning each particular item, and no great effort is required to "whip" the article into shape.

PARAGRAPHING AND LOGICAL SEQUENCE

In the preparation of technical articles which will require considerable effort in reading, there are a number of considerations which should be kept in mind. Each idea expressed should be, as far as possible, more or less complete in itself, or when this is impossible, it should follow or be followed by others in logical sequence. It should not be necessary to go back some distance to pick up the thread of thought, nor should it be necessary to have it dependent upon some statement which is to appear later. Nothing is more irritating to the average reader than to be obliged, at frequent intervals, to go back and review some former part in order to obtain the meaning of certain sentences, statements or paragraphs. This, of course, does not refer to mathematical equations, for here it may not be practicable to make each part complete in itself.

Again, the material in any paragraph should be arranged in logical sequence. For instance, if there is a general description of certain apparatus and a detailed description of certain parts of it, the details should not come first, except in very special cases. If the effect is of primary importance and the cause is but an incidental part of the story, the effect may be described first. If, however, the result obtained is merely the effect of some cause which is to be brought out quite positively, then the cause should be given prominence. This phase of the subject should be given quite careful consideration by the technical writer.

As another condition, each paragraph should hold a closer relation to those which immediately precede and follow it, than to those further away. Otherwise, there is a break in the line of thought and such breaks are usually distasteful to the reader. Also, each paragraph, while it should be more or less complete in itself, should not be absolutely independent of what immediately precedes or follows; otherwise, the article may

seem to be made up of a number of isolated statements, and it then gives the impression of being an assemblage of separate notes or items. The paper should read as one continous subject.

Like fiction, as developed in novels and short stories, the technical article should have a good beginning and a good ending. It should appear to be complete in itself and should not give the impression of a few pages cut out of the body of a longer paper. Incomplete beginnings or endings in fiction are for the purpose of giving startling effects, but such do not belong to technical literature.

CLEARNESS IN SENTENCE STRUCTURE

One difficulty with many technical papers is that they are not definitely clear in meaning. The arrangement of sentences and words should be such as make sure that the proper meaning will be obtained at first glance. A sentence may be so long or so involved that one must read it several times to get the meaning. When a sentence becomes so long that it is difficult to follow the fundamental idea, it should be reorganized, and preferably split into two or more shorter sentences. It should be borne in mind that many of us read purely for the idea or meaning, not the words or language; and if we are forced to turn our attention to the "make up" of the sentences, we break or lose the train of thought. In a well written technical article, of a non-mathematical nature, the reader should be able to pass from sentence to sentence, idea to idea, paragraph to paragraph, without noticing particularly the rhetorical machinery, so to speak.

STYLE

In technical papers, written primarily for instructional purposes, a dignified style should be maintained. Humorous styles, expressions, language or dialects are inappropriate. Humor is intended primarily for entertainment, with the idea of merriment uppermost. Usually merriment and instruction do not pull side by side. However, humorous incidents, having a direct bearing on the subject matter, may be included at times, if the style of article is one which will permit them, such as descriptive, reminiscent, and semi-historical papers, etc.

It is necessary to distinguish between matters intended primarily for instructional purposes, and those which can be considered as being principally of an advertising nature. In the latter, unusual or startling effects are allowable, to attract attention. Likewise, humor, dialect, unusual language or expression may all serve the principal purpose in view. But such articles should not be considered as literature, in the orthodox sense.

USE OF MATHEMATICS

One fault with many technical writers is that they seek opportunity to incorporate visible mathematics in their articles under the impression that their papers are thus more technical. This may be permissible where the prime purpose of the article is an exhibition of "mathematical gymnastics". To the average reader, mathematics are bad enough, even when absolutely necessary. Therefore, the inclusion of mathematical formulæ, in many cases, serves to drive the reader away. However, most technical men have a fair grasp of mathematical principles, outside of the formulæ, and it often happens that they will read a more or less mathematical treatise if no formulæ are visible and the subject material appears to be plain reading matter.

Mathematics may be considered, in many cases, as simply the tools with which the technical man accomplishes a desirable result; and when the result, only, is of importance, the methods, or tools, need not be given. In exhibiting a piece of statuary, for instance, the sculptor usually does not show the tools of his art as a principal part of the work. Of course, such a comparison must not be carried too far, for not infrequently the main intent of the technical writer is to show to others the method of arriving at a certain result; or, in other words, the tools or machinery which represent his method, actually form the primary exhibit.

Referring again to visible mathematics, it has been said that, in many cases, a mathematical equation is simply a short-hand statement of some fact. If such fact itself were stated in simple language, the average reader would accept it on faith, just as readily as he would accept the mathematical equation. But what is more important, he would probably sense its meaning, which often would not be the case with a formula or equation. It has been said, with considerable truth, that it takes a fairly good mathematician to write a mathematical paper without the reader being aware of the fact.

BREVITY

While brevity may be "the soul of wit", yet it is not necessarily the soul of a technical article,—rather the opposite, in many cases. Cutting out pertinent material, just to abbreviate an article, is even worse than padding it with useless "stuff" in order to lengthen it. In fiction it may be all right to leave much to the imagination, but when one reads a technical paper, he is after facts, and enough of them must be included, to make a clear presentation of the subject in hand. A paper which covers only the "high spots" and leaves the intervening valleys to be filled by the reader's imagination cannot be considered as very satisfactory, when it comes to technical writing.

CONCLUSION

In conclusion, it may be noted that all the foregoing suggestions have to do with the mechanics, so to speak, of technical writing. How to produce the ideas and how to put them on paper, are matters whose explanation is beyond the writer's capabilities. Practice and experience have much to do with making the paper thoroughly readable, but if it is to be worth while, the ideas must also be there. To put the case in plain English, if one has no definite ideas on a given subject, he should not attempt to write about it.

Electrical Characteristics of Transmission Circuits-III

Quick Estimating Tables

Wm. Nesbit

For every occasion where a complete calculation of a long distance transmission line is made, there are many where the size of wire needed to transmit a given amount of power economically is required quickly. This knowledge is, moreover, the basis for all transmission line calculations, as all methods of calculating regulation presuppose that the size of wire is known. To determine quickly and with the least possible calculation the approximate size of conductor corresponding to a given I^2R transmission loss for any ordinary voltage or distance, is the function of Tables XII to XXI inclusive. By including so many transmission voltages it is not intended to indicate that any of them might equally well be selected for a new installation. On the contrary it is very desirable in the consideration of a new installation, to eliminate consideration of some of the voltages now in use. This point will be considered later.

Since both the power-factor of the load, and the charging current of the circuit, as well as any change in the resistance of the conductors, will alter the I^2R loss, it is evident that it is impractical to present tables which will take into account the effect of all of these variables. The accompanying tables do, however, give the percentage I^2R loss corresponding to the two temperatures (25 and 65 degrees C) ordinarily encountered in practice and the usual load power-factors of unity and 80 percent lagging, upon which the k.v.a. values of the tables are based. The effect, however, of charging current, corona or leakage loss is not taken into account in these table values. The latter two (corona and leakage) are usually small and need not be considered here. The effect of charging current, may, however, with long circuits be material and will be discussed.

The values of k.v.a. in these tables are based upon the following percentage I^2R loss in transmission (neglecting the effect of charging current):—

	Percent Loss At 25°C	Percent Loss At 65°C
Load at 100 percent P-F.	8.66	10.0
Load at 80 percent P-F.	10.8	12.5

These loss values are based upon the power delivered at the end of the circuit as 100 percent, and not upon the power at the supply end. If raising or lowering transformers are employed, the loss and voltage drop in them will, of course, be in addition to the above.

At first glance, some of these tables may appear to have been carried to extremes of k.v.a. values for the conductor sizes. This is because the tables are calculated for ten percent loss, (at 100 percent power-factor and 65 degrees C) whereas the permissible loss is frequently much less than ten percent. As the loss is directly proportional to the load, the permissible loads for a given size wire and distance can be read almost directly for any loss. Thus for a two percent loss the permissible k.v.a. will be two-tenths the table values. Conversely, the size of wire to carry a given k.v.a. load at two percent loss will be the same as will carry five ($10 \div 2$) times the k.v.a. at ten percent loss. In other words to find the size of wire to carry a given k.v.a. load at any desired percent loss, find the ratio of the desired I^2R loss to the I^2R loss upon which the table values are based (corresponding of course to the temperature and the load power-factor). Divide this ratio into the k.v.a. to be transmitted. The result will be the table k.v.a. value corresponding to the desired I^2R loss.

For example:—Assume 400 k.v.a. is to be delivered a distance of 14 miles at 6000 volts, three-phase, and 80 percent power-factor lagging, at an assumed temperature of 25 degrees C. Table XV indicates that this condition will be met with an I^2R loss of 10.8 percent if No. 0 copper or 167 800 circ. mil aluminum conductors are used.

Now assume that the I^2R loss should not exceed 5.4 percent, in place of 10.8 percent (upon which the table values are based). $5.4 \div 10.8 = 0.5$ and $400 \div 0.5 = 800$ k.v.a. as the table value corresponding to an I^2R loss of 5.4 percent. The conductors corresponding to 800 k.v.a. table value (5.4 percent I^2R loss) will be seen to be No. 0000 copper or 336 420 circ. mil aluminum.

If conductors corresponding to 15 percent I^2R loss are desired the same procedure will be followed:— $15 \div 10.8 = 1.39$ and $400 \div 1.39 = 287$ k.v.a. table value. This table value corresponds to approximately No. 1 copper or 133 220 circ. mil aluminum conductors.

The table k.v.a. values have been tabulated for various distances. Should the actual distance be different from the table values and it is desired to obtain k.v.a. values corresponding to the losses upon which the table k.v.a. values have been calculated, the following procedure may be followed:—

For a given I^2R loss in a given conductor (effect of charging current neglected) the k.v.a. $\times$ feet or the k.v.a. $\times$ miles is a constant. Thus Table XII indicates that for 2 000 000 circ. mil cable, 756 000 k.v.a. $\times$ feet is the constant; that is 756 k.v.a. may be transmitted 1000 feet; 378 k.v.a., 2000 feet, and so on. If the actual distance to be transmitted is 1300 feet the corresponding k.v.a. value will be $756\,000 \div 1300$ or 581 k.v.a. Usually the k.v.a. value can readily be approximated

for any distance with sufficient accuracy for the purpose for which these quick estimating tables are presented. One way of dong this would be as follows:— The k.v.a. value corresponding to 2500 ft. is 302 k.v.a.

TABLE XII—QUICK ESTIMATING TABLE

KILOVOLT-AMPERES, 3 PHASE, WHICH MAY BE DELIVERED AT THE FOLLOWING VOLTAGES OVER THE VARIOUS CONDUCTORS FOR THE DISTANCES STATED. BASED UPON THE FOLLOWING I^2R LOSS (EFFECT OF CHARGING CURRENT NEGLECTED)

	AT 25° C	AT 65° C
FOR LOAD POWER-FACTOR OF 100%	8.66% LOSS	10.0% LOSS
FOR LOAD POWER-FACTOR OF 80%	10.8% LOSS	12.5 LOSS

220 VOLTS DELIVERED

B & S NO.	COPPER AREA IN CIRCULAR MILS	ALUMINUM AREA IN CIRCULAR MILS	50 FEET	100 FEET	150 FEET	200 FEET	250 FEET	300 FEET	400 FEET	500 FEET	600 FEET	750 FEET	1000 FEET	1500 FEET	2000 FEET	2500 FEET	3500 FEET	5000 FEET	1 MILE
	2 000 000		15125	7562	5042	3781	3025	2521	1890	1512	1260	1008	756	504	378	302	216	151	143
	1 800 000		13730	6865	4577	3432	2746	2288	1716	1373	1144	915	686	458	343	274	196	137	130
	1 700 000		12821	6410	4274	3205	2564	2137	1602	1282	1068	855	641	427	320	256	183	128	121
	1 600 000		12100	6050	4033	3025	2420	2016	1512	1210	1008	806	605	403	302	242	173	121	114
	1 500 000		11321	5660	3774	2830	2264	1887	1415	1132	943	755	566	377	283	226	162	113	107
	1 400 000		10579	5289	3526	2644	2116	1763	1322	1058	881	705	529	353	264	211	151	106	100
	1 200 000		9047	4523	3015	2262	1809	1507	1131	905	753	603	452	301	226	181	129	90	85
	1 100 000		8345	4172	2782	2086	1669	1391	1043	834	695	556	417	278	209	167	119	83	78
	1 000 000	1 590 000	7562	3781	2521	1890	1512	1260	945	756	630	504	378	252	189	151	108	76	72
	950 000	1 515 000	7224	3612	2408	1806	1445	1204	903	722	602	482	361	241	181	144	103	72	68
	900 000	1 431 000	6817	3408	2272	1704	1363	1136	852	682	568	454	341	227	170	136	98	68	64
	850 000	1 351 500	6410	3205	2136	1602	1282	1068	801	641	534	427	320	214	160	128	91	64	61
	800 000	1 272 000	6050	3025	2017	1512	1210	1008	756	605	504	403	302	202	151	121	86	60	57
	750 000	1 192 500	5678	2839	1893	1420	1135	947	710	568	473	378	284	189	142	113	81	57	54
	700 000	1 113 000	5290	2645	1763	1322	1058	881	661	529	440	353	264	176	132	105	75	53	50
	650 000	1 033 500	4914	2457	1638	1228	983	819	614	491	409	328	246	164	123	98	70	49	45
	600 000	954 000	4523	2262	1507	1131	905	753	565	452	376	302	226	151	113	90	64	45	43
	550 000	874 500	4173	2086	1391	1043	834	695	522	417	347	278	209	139	104	83	59	42	39
	500 000	795 000	3781	1890	1260	945	756	630	472	378	315	252	189	126	94	75	54	38	36
	450 000	715 500	3396	1698	1132	849	679	566	425	340	283	226	170	113	85	68	49	34	32
	400 000	636 000	3034	1517	1011	758	607	505	379	303	252	202	152	101	76	60	43	30	29
	350 000	556 500	2645	1322	882	661	529	441	330	264	220	176	132	88	66	53	38	26	25
	300 000	477 000	2267	1133	755	567	453	378	283	227	189	151	113	75	57	45	32	23	21
	250 000	397 500	1898	949	633	474	379	316	237	190	158	126	95	63	47	38	27	19	18
0000	211 600	336 420	1600	800	533	400	320	266	200	160	133	107	80	53	40	32	23	16	15
000	167 772	266 800	1274	637	425	318	255	212	159	127	106	85	64	42	32	25	18	13	12
00	133 079	211 950	1008	504	336	252	202	168	126	101	84	67	50	34	25	20	14	10	9
0	105 560	167 800	800	400	266	200	160	133	100	80	66	53	40	27	20	16	11	8	8
1	83 694	133 220	632	316	211	158	126	106	79	63	53	42	32	21	16	12	9	6	6
2	66 358	105 530	501	250	167	125	100	83	62	50	41	33	25	17	12	10	7	5	5
3	52 624	83 640	396	198	132	99	79	66	49	40	33	26	20	13	10	8	6	4	4
4	41 738	66 370	316	158	105	79	63	52	39	32	26	21	16	10	8	6	5	3	3
5	33 088	52 630	251	125	84	62	50	42	31	25	21	16	12	8	6	5	4	2	2
6	26 244	41 740	198	99	66	50	40	33	25	20	16	13	10	6	5	4	3	2	2
7	20 822		157	78	52	39	31	26	20	16	13	10	8	5	4	3	2	1	1
8	16 512		125	62	42	31	25	21	15	12	10	8	6	4	3	2	2	1	1

440 VOLTS DELIVERED

B & S NO.	COPPER AREA IN CIRCULAR MILS	ALUMINUM AREA IN CIRCULAR MILS	50 FEET	100 FEET	150 FEET	200 FEET	250 FEET	300 FEET	400 FEET	500 FEET	600 FEET	750 FEET	1000 FEET	1500 FEET	2000 FEET	2500 FEET	3500 FEET	5000 FEET	1 MILE
	2 000 000		60500	30250	20166	15125	12100	10083	7562	6050	5042	4033	3025	2017	1512	1210	864	605	573
	1 800 000		54922	27461	18307	13730	10988	9153	6865	5492	4576	3648	2746	1831	1373	1094	784	549	520
	1 700 000		51285	25642	17095	12821	10257	8547	6410	5128	4273	3419	2564	1710	1282	1026	732	513	485
	1 600 000		48400	24200	16133	12100	9680	8066	6050	4840	4033	3226	2420	1613	1210	968	691	484	458
	1 500 000		45286	22643	15095	11322	9057	7547	5661	4528	3773	3019	2264	1510	1132	906	646	453	429
	1 400 000		42317	21158	14105	10579	8463	7052	5289	4231	3526	2821	2115	1410	1057	846	604	423	400
	1 200 000		36187	18093	12062	9047	7237	6031	4523	3618	3015	2412	1809	1206	904	724	517	362	343
	1 100 000		33379	16687	11126	8344	6676	5563	4172	3337	2782	2225	1668	1113	834	668	477	334	315
	1 000 000	1 590 000	30250	15125	10083	7562	6050	5042	3781	3025	2521	2016	1512	1008	756	605	432	302	287
	950 000	1 515 000	28896	14448	9632	7224	5779	4816	3612	2889	2408	1926	1444	963	722	578	412	289	273
	900 000	1 431 000	27268	13634	9089	6817	5453	4544	3408	2726	2272	1817	1363	909	682	545	389	273	258
	850 000	1 351 500	25642	12821	8547	6410	5128	4273	3205	2564	2136	1709	1282	855	641	513	366	256	243
	800 000	1 272 000	24200	12100	8066	6050	4840	4033	3025	2420	2016	1613	1210	807	605	484	346	242	226
	750 000	1 192 500	22710	11355	7570	5677	4542	3785	2838	2271	1892	1514	1135	757	567	454	324	227	215
	700 000	1 113 000	21158	10579	7053	5289	4231	3527	2644	2115	1763	1410	1057	705	528	423	302	211	201
	650 000	1 033 500	19655	9827	6552	4913	3931	3276	2456	1965	1638	1310	982	655	491	393	281	196	186
	600 000	954 000	18093	9046	6031	4523	3618	3015	2261	1809	1507	1206	904	603	452	362	258	181	171
	550 000	874 500	16690	8345	5563	4172	3338	2781	2086	1669	1390	1113	834	556	417	334	238	167	158
	500 000	795 000	15125	7562	5042	3781	3025	2521	1890	1512	1260	1008	756	504	378	302	216	151	143
	450 000	715 500	13586	6793	4529	3396	2717	2264	1698	1358	1132	905	679	453	340	272	194	139	129
	400 000	636 000	12138	6069	4046	3034	2427	2023	1517	1213	1012	809	607	405	303	243	173	121	115
	350 000	556 500	10579	5289	3526	2644	2115	1763	1322	1058	881	705	529	353	264	211	151	106	100
	300 000	477 000	9068	4534	3023	2267	1813	1512	1133	906	756	604	453	302	226	181	129	91	86
	250 000	397 500	7592	3796	2531	1898	1518	1265	949	759	632	506	379	253	189	152	108	76	72
0000	211 600	336 420	6400	3200	2133	1600	1280	1067	800	640	533	426	320	213	160	128	91	64	61
000	167 772	266 800	5095	2547	1698	1273	1019	849	636	509	425	339	254	170	127	102	73	51	48
00	133 079	211 950	4033	2016	1344	1008	806	672	504	403	336	268	202	134	101	81	58	40	38
0	105 560	167 800	3200	1600	1066	800	640	533	400	320	266	213	160	107	80	64	46	32	30
1	83 694	133 220	2530	1265	843	632	506	422	316	253	211	169	127	84	63	51	36	25	24
2	66 358	105 530	2006	1003	669	501	401	334	250	200	167	134	100	67	50	40	28	20	19
3	52 624	83 640	1586	793	529	396	317	264	198	158	132	105	79	53	40	32	22	16	15
4	41 738	66 370	1265	632	423	316	253	212	158	126	106	84	63	42	32	25	18	13	12
5	33 088	52 630	1003	502	334	253	201	167	125	100	83	67	50	33	25	20	14	10	9
6	26 244	41 740	791	395	264	197	158	132	98	79	66	53	39	26	20	16	11	8	8
7	20 822		629	314	210	157	126	105	78	63	52	41	32	21	16	15	9	6	6
8	16 512		500	250	166	125	100	83	62	50	42	33	25	17	12	10	7	5	5

The heating limitations may, for the shorter distances, particularly if insulated or concealed conductors are employed, necessitate the use of larger conductors, resulting in a correspondingly less transmission loss. In the case of insulated or concealed conductors, should the k.v.a. values fall near or to the left of the heavy line, consult Table XXV for insulated or Table XXIII for bare conductors. The reactance for the larger conductors may be excessive, particularly for 60-cycle service, producing excessive voltage drop. This may be obviated by installing two or more parallel circuits or using three-conductor cables. For single-phase circuits the k.v.a. will be one-half the table values.

Hence the value corresponding to half this distance (1250 ft.) is [illegible] k.v.a., which is sufficiently accurate for practical purposes.

REACTANCE LIMITATIONS

The k.v.a. value of the tables naturally do not take into account the reactance of the circuit. It will be

TABLE XIII—QUICK ESTIMATING TABLE

KILOVOLT-AMPERES, 3 PHASE, WHICH MAY BE DELIVERED AT THE FOLLOWING VOLTAGES OVER THE VARIOUS CONDUCTORS FOR THE DISTANCES STATED. BASED UPON THE FOLLOWING I^2R LOSS (EFFECT OF CHARGING CURRENT NEGLECTED)

	AT 25° C	AT 65° C
FOR LOAD POWER-FACTOR OF 100%	8.66% LOSS	10.0% LOSS
FOR LOAD POWER-FACTOR OF 80%	10.8% LOSS	12.5 LOSS

550 VOLTS DELIVERED

B & S NO.	COPPER AREA IN CIRCULAR MILS	ALUMINUM AREA IN CIRCULAR MILS	50 FEET	100 FEET	150 FEET	200 FEET	250 FEET	300 FEET	400 FEET	500 FEET	600 FEET	750 FEET	1000 FEET	1500 FEET	2000 FEET	2500 FEET	3500 FEET	5000 FEET	1 MILE
	2 000 000		94531	47266	31510	23633	18906	15755	11816	9453	7877	6302	4727	3151	2363	1891	1350	945	896
	1 800 000		85815	42907	28605	21453	17163	14302	10727	8581	7151	5721	4291	2860	2145	1716	1226	858	812
	1 700 000		80132	40066	26711	20033	16026	13355	10016	8013	6677	5342	4007	2671	2003	1603	1144	801	758
	1 600 000		75625	37812	25208	18906	15125	12604	9453	7562	6302	5042	3781	2521	1891	1512	1081	756	716
	1 500 000		70760	35380	23587	17690	14152	11793	8845	7076	5896	4717	3538	2353	1769	1415	1011	708	670
	1 400 000		66120	33060	22040	16530	13224	11020	8265	6612	5510	4408	3306	2204	1653	1322	945	661	625
	1 200 000		56542	28271	18847	14135	11308	9423	7067	5654	4711	3769	2827	1885	1413	1131	808	565	535
	1 100 000		52155	26077	17385	13038	10431	8692	6519	5215	4346	3477	2608	1738	1304	1043	745	522	492
	1 000 000	1 590 000	47265	23632	15755	11816	9453	7877	5908	4727	3938	3151	2363	1576	1182	945	675	473	448
	950 000	1 515 000	45149	22574	15050	11287	9030	7525	5643	4515	3762	3010	2257	1505	1129	903	645	452	426
	900 000	1 431 000	42606	21303	14202	10652	8521	7101	5326	4260	3550	2840	2130	1420	1065	852	608	426	403
	850 000	1 351 500	40066	20033	13355	10016	8013	6677	5008	4007	3338	2671	2003	1336	1002	801	572	401	380
	800 000	1 272 000	37813	18907	12604	9453	7562	6302	4727	3781	3151	2521	1891	1260	945	756	540	378	358
	750 000	1 192 500	35484	17742	11828	8871	7097	5914	4435	3548	2957	2366	1774	1183	887	708	507	355	335
	700 000	1 113 000	33060	16530	11020	8265	6612	5510	4132	3306	2755	2204	1653	1102	827	661	472	331	313
	650 000	1 033 500	30710	15355	10237	7677	6142	5118	3838	3071	2559	2047	1535	1024	868	614	439	307	291
	600 000	954 000	28271	14135	9424	7067	5654	4712	3533	2827	2356	1884	1414	942	707	565	404	283	268
	550 000	874 500	26078	13039	8693	6520	5215	4346	3260	2607	2173	1738	1304	869	652	522	372	261	247
	500 000	795 000	23633	11816	7878	5908	4726	3939	2954	2363	1969	1575	1182	788	591	473	337	236	224
	450 000	715 500	21228	10614	7076	5307	4246	3538	2653	2123	1769	1415	1061	708	531	425	303	212	201
	400 000	636 000	18965	9482	6322	4741	3793	3161	2370	1896	1580	1264	948	632	474	379	271	190	180
	350 000	556 500	16530	8265	5510	4132	3306	2755	2066	1653	1377	1103	826	551	413	331	236	165	156
	300 000	477 000	14168	7084	4723	3542	2823	2361	1771	1416	1180	944	708	472	354	283	202	142	134
	250 000	397 500	11863	5932	3954	2966	2372	1977	1483	1186	988	791	593	395	297	237	170	119	112
0000	211 600	336 420	10000	5000	3333	2500	2000	1666	1250	1000	833	666	500	333	250	200	143	100	95
000	167 772	266 800	7960	3980	2653	1990	1592	1327	995	796	663	531	398	265	199	159	113	80	75
00	133 079	211 950	6302	3151	2101	1575	1260	1050	787	630	525	420	315	210	158	126	90	63	60
0	105 560	167 800	5000	2500	1666	1250	1000	833	625	500	416	333	250	166	125	100	71	50	47
1	83 694	133 220	3954	1977	1318	988	791	659	494	395	329	264	198	132	99	79	56	40	38
2	66 358	105 530	3134	1567	1045	783	627	522	392	313	261	209	157	105	78	63	45	31	30
3	52 624	83 640	2479	1239	826	620	496	413	310	248	207	165	124	83	62	50	35	25	24
4	41 738	66 370	1977	988	659	494	395	329	297	197	164	132	99	66	49	40	28	20	19
5	33 088	52 630	1567	783	522	392	313	261	196	156	130	104	78	52	39	31	22	16	15
6	26 244	41 740	1239	619	413	310	247	206	155	123	103	82	61	41	31	25	18	12	12
7	20 822		984	492	328	246	197	164	123	98	82	65	49	33	25	20	14	10	9
8	16 512		780	390	260	195	156	130	97	78	65	52	39	26	20	16	11	8	7

1100 VOLTS DELIVERED

B & S NO.	COPPER AREA IN CIRCULAR MILS	ALUMINUM AREA IN CIRCULAR MILS	100 FEET	200 FEET	300 FEET	500 FEET	750 FEET	1000 FEET	2500 FEET	4000 FEET	1 MILE	1¼ MILES	1½ MILES	2 MILES	2½ MILES	3 MILES	3½ MILES	4 MILES	5 MILES
	2 000 000		189062	94531	63021	37812	25208	18906	7562	4726	3580	2865	2388	1790	1432	1194	1023	895	716
	1 800 000		171631	85815	57210	34326	22884	17163	6865	4291	3250	2600	2166	1625	1300	1083	928	812	650
	1 700 000		160265	80132	53424	32053	21368	16026	6410	4006	3035	2428	2023	1517	1214	1012	867	758	607
	1 600 000		151250	75625	50416	30250	20166	15125	6050	3781	2865	2291	1910	1432	1145	955	818	716	572
	1 500 000		141520	70760	47173	28304	18868	14152	5661	3538	2680	2144	1786	1340	1072	893	766	670	536
	1 400 000		132240	66120	44080	26448	17631	13224	5289	3306	2505	2003	1669	1252	1002	834	716	626	501
	1 200 000		113084	56542	37694	22617	15078	11308	4523	2827	2141	1713	1428	1070	856	714	612	535	428
	1 100 000		104310	52155	34770	20862	13908	10431	4172	2608	1976	1580	1317	988	790	658	565	494	395
	1 000 000	1 590 000	94531	47265	31510	18906	12604	9453	3781	2363	1790	1432	1194	895	716	597	512	447	358
	950 000	1 515 000	90298	45149	30099	18059	12040	9030	3612	2257	1710	1368	1140	855	684	570	489	427	342
	900 000	1 431 000	85211	42605	28404	17042	11361	8521	3408	2130	1613	1291	1076	807	645	538	461	403	322
	850 000	1 351 500	80132	40066	26711	16026	10684	8013	3205	2003	1518	1214	1012	759	607	506	434	379	303
	800 000	1 272 000	75625	37814	25209	15126	10083	7563	3025	1891	1432	1146	955	716	573	477	409	358	286
	750 000	1 192 500	70968	35484	23656	14193	9462	7097	2839	1774	1344	1075	896	672	537	448	384	336	268
	700 000	1 113 000	66120	33060	22040	13224	8816	6612	2645	1653	1252	1002	835	626	501	417	358	313	250
	650 000	1 033 500	61421	30710	20474	12284	8189	6142	2457	1535	1163	930	775	582	466	388	332	291	232
	600 000	954 000	56542	28271	18847	11308	7539	5654	2261	1413	1071	856	714	535	428	357	306	267	214
	550 000	874 500	52155	26077	17385	10431	6954	5215	2086	1304	988	790	658	494	395	329	282	247	197
	500 000	795 000	47265	23632	15755	9453	6302	4726	1890	1181	895	716	597	447	358	298	256	223	179
	450 000	715 500	42456	21228	14152	8491	5661	4246	1698	1061	804	643	536	402	322	268	229	201	161
	400 000	636 000	37931	18965	12644	7586	5057	3793	1517	948	718	575	479	359	287	239	205	179	143
	350 000	556 500	33060	16530	11020	6612	4408	3306	1322	826	626	501	417	313	250	208	179	156	125
	300 000	477 000	28337	14168	9446	5667	3778	2833	1133	708	536	430	358	268	215	179	153	134	107
	250 000	397 500	23725	11862	7908	4745	3163	2372	949	593	449	359	300	224	179	150	128	112	89
0000	211 600	336 420	20000	10000	6666	4000	2666	2000	800	500	378	303	252	189	152	126	109	94	76
000	167 772	266 800	15921	7960	5307	3184	2123	1592	637	398	301	241	201	150	120	100	86	75	60
00	133 079	211 950	12604	6302	4201	2521	1680	1260	504	315	238	191	159	119	95	79	68	59	47
0	105 560	167 800	10000	5000	3333	2000	1333	1000	400	250	190	151	126	95	75	63	54	47	37
1	83 694	133 200	7908	3954	2636	1581	1054	791	316	198	150	120	100	75	60	50	42	37	30
2	66 358	105 530	6269	3134	2089	1254	835	627	251	157	118	95	79	59	47	39	34	29	23
3	52 624	83 640	4968	2479	1653	991	661	496	198	124	94	75	62	47	37	31	26	23	18
4	41 738	66 370	3954	1977	1318	791	527	395	158	99	75	60	50	37	30	25	21	18	15
5	33 088	52 630	3134	1567	1045	627	418	313	125	78	59	47	40	29	23	20	17	14	12
6	26 244	41 740	2479	1239	826	496	330	248	99	62	47	37	31	23	18	15	14	12	9
7	20 822		1967	983	655	393	262	197	78	49	37	30	25	18	15	12	10	9	7
8	16 512		1561	780	520	312	208	156	62	39	30	24	20	15	12	10	8	7	6

The heating limitations may, for the shorter distances, particularly if insulated or concealed conductors are employed, necessitate the use of larger conductors, resulting in a correspondingly less transmission loss. In the case of insulated or concealed conductors, should the k.v.a. values fall near or to the left of the heavy line, consult Table XXV for insulated or Table XXIII for bare conductors. The reactance for the larger conductors may be excessive, particularly for 60-cycle service, producing excessive voltage drop. This may be obviated by installing two or more parallel circuits or using three-conductor cables. For single-phase circuits the k.v.a. will be one-half the table values.

necessary in some cases of low voltage and single conductors (where the reactance is high) to use lower values of k.v.a. or even in some cases to multiple circuits in order to keep the reactance within satisfactory operating limits. This will be considered later by examples on voltage regulation.

TABLE XIV—QUICK ESTIMATING TABLE

CONDUCTORS

KILOVOLT-AMPERES, 3 PHASE, WHICH MAY BE DELIVERED AT THE FOLLOWING VOLTAGES OVER THE VARIOUS CONDUCTORS FOR THE DISTANCES STATED. BASED UPON THE FOLLOWING I^2R LOSS (EFFECT OF CHARGING CURRENT NEGLECTED)

	AT 25° C	AT 65° C
FOR LOAD POWER-FACTOR OF 100%	8.66% LOSS	10.0% LOSS
FOR LOAD POWER-FACTOR OF 80%	10.8% LOSS	12.5 LOSS

2200 VOLTS DELIVERED

B & S NO.	COPPER AREA IN CIRCULAR MILS	ALUMINUM AREA IN CIRCULAR MILS	100 FEET	200 FEET	300 FEET	500 FEET	750 FEET	1000 FEET	2500 FEET	4000 FEET	1 MILE	1¼ MILES	1½ MILES	2 MILES	2½ MILES	3 MILES	3½ MILES	4 MILES	5 MILES
	2 000 000		756 000	378 000	252 000	151 000	101 000	75 600	30 200	18 900	14 300	11 460	9 550	7 160	5 730	4 770	4 090	3 580	2 860
	1 800 000		686 000	343 000	229 000	137 000	91 500	68 600	27 400	17 100	13 000	10 400	8 670	6 500	5 200	4 330	3 710	3 250	2 600
	1 700 000		641 000	320 000	214 000	128 000	85 500	64 100	25 600	16 000	12 100	9 710	8 100	6 070	4 850	4 050	3 470	3 040	2 430
	1 600 000		605 000	302 000	202 000	121 000	80 700	60 500	24 200	15 100	11 400	9 170	7 640	5 730	4 580	3 820	3 270	2 860	2 290
	1 500 000		566 000	283 000	189 000	113 000	75 500	56 600	22 600	14 100	10 700	8 580	7 150	5 360	4 290	3 570	3 060	2 680	2 140
	1 400 000		529 000	264 000	176 000	106 000	70 500	52 900	21 100	13 200	10 000	8 010	6 680	5 010	4 010	3 340	2 860	2 500	2 000
	1 200 000		452 000	226 000	151 000	90 500	60 300	45 200	18 100	11 300	8 560	6 850	5 710	4 280	3 430	2 850	2 450	2 140	1 710
	1 100 000		417 000	208 000	139 000	83 400	55 600	41 700	16 700	10 400	7 900	6 320	5 270	3 950	3 160	2 630	2 260	1 970	1 580
	1 000 000	1 590 000	378 000	189 000	126 000	75 600	50 400	37 800	15 100	9 450	7 160	5 730	4 770	3 580	2 860	2 390	2 040	1 790	1 430
	950 000	1 515 000	361 000	180 000	120 000	72 200	48 100	36 100	14 400	9 030	6 840	5 470	4 560	3 420	2 740	2 280	1 950	1 710	1 370
	900 000	1 431 000	341 000	170 000	114 000	68 100	45 400	34 100	13 600	8 520	6 450	5 160	4 300	3 230	2 580	2 150	1 840	1 610	1 290
	850 000	1 351 500	320 000	160 000	107 000	64 100	42 700	32 000	12 800	8 010	6 070	4 860	4 050	3 030	2 430	2 020	1 730	1 520	1 210
	800 000	1 272 000	302 000	151 000	101 000	60 500	40 300	30 200	12 100	7 560	5 730	4 580	3 820	2 860	2 290	1 910	1 640	1 430	1 146
	750 000	1 192 500	284 000	142 000	94 600	56 800	37 800	28 400	11 300	7 100	5 370	4 300	3 580	2 700	2 150	1 790	1 540	1 340	1 070
	700 000	1 113 000	264 000	132 000	88 100	52 900	35 200	26 400	10 600	6 610	5 010	4 010	3 340	2 500	2 000	1 670	1 430	1 250	1 000
	650 000	1 033 500	246 000	123 000	81 900	49 100	32 700	24 500	9 800	6 140	4 650	3 720	3 100	2 330	1 861	1 550	1 330	1 160	931
	600 000	954 000	226 000	113 000	75 400	45 200	30 100	22 600	9 050	5 650	4 280	3 430	2 850	2 140	1 710	1 430	1 220	1 070	857
	550 000	874 500	208 000	104 000	69 500	41 700	27 800	20 800	8 350	5 210	3 950	3 160	2 630	1 970	1 580	1 310	1 130	987	790
	500 000	795 000	189 000	94 500	63 000	37 800	25 200	18 900	7 560	4 730	3 580	2 860	2 380	1 790	1 430	1 190	1 020	895	716
	450 000	715 500	170 000	84 900	56 600	33 900	22 600	17 000	6 800	4 240	3 220	2 570	2 140	1 610	1 290	1 070	920	804	643
	400 000	636 000	152 000	75 800	50 600	30 300	20 200	15 200	6 070	3 790	2 870	2 300	1 910	1 440	1 150	958	824	718	575
	350 000	556 500	132 000	66 100	44 100	26 400	17 600	13 200	5 290	3 310	2 500	2 000	1 670	1 250	1 000	835	716	626	501
	300 000	477 000	113 000	56 700	37 800	22 700	15 100	11 300	4 530	2 830	2 150	1 720	1 430	1 073	860	715	613	536	429
	250 000	397 500	94 900	47 400	31 600	19 000	12 600	9 500	3 800	2 370	1 800	1 440	1 200	900	720	600	513	450	359
0000	211 600	336 420	80 000	40 000	26 700	16 000	10 700	8 000	3 200	2 000	1 510	1 210	1 010	757	606	505	433	378	303
000	167 772	266 800	63 700	31 800	21 200	12 700	8 490	6 370	2 550	1 590	1 200	965	804	603	482	402	345	301	241
00	133 079	211 950	50 400	25 200	16 800	10 100	6 720	5 040	2 000	1 260	955	760	636	477	382	318	273	238	191
0	105 560	167 800	40 000	20 000	13 300	8 000	5 330	4 000	1 600	1 000	757	606	505	380	303	252	217	189	151
1	83 694	133 220	31 600	15 800	10 500	6 330	4 220	3 160	1 260	790	600	480	400	300	239	200	171	150	120
2	66 358	105 530	25 100	12 500	8 360	5 010	3 340	2 510	1 000	630	475	380	317	237	190	158	136	118	95
3	52 624	83 640	19 800	9 900	6 610	3 970	2 640	1 980	790	500	375	300	250	188	150	125	107	94	75
4	41 738	66 370	15 800	7 910	5 270	3 160	2 110	1 580	630	395	300	240	200	150	120	100	86	75	60
5	33 088	52 630	12 500	6 270	4 180	2 510	1 670	1 250	500	313	237	190	159	118	95	79	68	59	47
6	26 244	41 740	9 900	4 960	3 310	1 980	1 320	990	400	250	188	150	125	94	75	63	54	47	37
7	20 822		7 900	3 930	2 620	1 570	1 050	790	310	197	149	119	99	74	59	49	42	37	30
8	16 512		6 250	3 120	2 080	1 250	830	620	250	156	118	95	79	59	47	39	34	30	24

4000 VOLTS DELIVERED

B & S NO.	COPPER	ALUMINUM	1 MILE	1½ MILES	2 MILES	2½ MILES	3 MILES	3½ MILES	4 MILES	5 MILES	6 MILES	7 MILES	8 MILES	9 MILES	10 MILES	11 MILES	12 MILES	13 MILES	14 MILES
	650 000	1 033 000	15 400	10 250	7 700	6 150	5 120	4 400	3 850	3 080	2 560	2 200	1 920	1 710	1 540	1 400	1 280	1 180	1 100
	600 000	954 000	14 200	9 460	7 100	5 670	4 750	4 050	3 550	2 840	2 370	2 030	1 775	1 580	1 420	1 290	1 180	1 090	1 020
	550 000	874 500	13 100	8 750	6 550	5 250	4 370	3 750	3 280	2 620	2 180	1 870	1 640	1 460	1 310	1 190	1 090	1 010	940
	500 000	795 000	11 900	7 950	5 950	4 750	3 960	3 400	2 980	2 380	1 980	1 700	1 490	1 320	1 190	1 080	990	915	850
	450 000	715 500	10 700	7 120	5 350	4 270	3 560	3 060	2 670	2 140	1 780	1 530	1 330	1 190	1 070	970	890	822	763
	400 000	636 000	9 490	6 330	4 750	3 800	3 165	2 713	2 373	1 900	1 582	1 357	1 186	1 055	949	863	791	736	678
	350 000	556 500	8 270	5 510	4 130	3 307	2 756	2 362	2 067	1 653	1 378	1 181	1 033	919	827	752	689	636	590
	300 000	477 000	7 080	4 720	3 540	2 832	2 359	2 023	1 769	1 416	1 179	1 011	884	786	708	644	589	545	506
	250 000	397 500	5 920	3 950	2 960	2 370	1 975	1 693	1 481	1 185	987	846	740	658	593	539	493	456	423
0000	211 600	336 420	5 000	3 330	2 500	2 000	1 666	1 428	1 250	1 000	833	714	625	555	500	454	416	385	357
000	167 772	266 800	3 980	2 650	1 990	1 592	1 326	1 137	995	796	663	568	497	442	398	362	331	306	284
00	133 079	211 950	3 140	2 090	1 570	1 255	1 046	896	783	627	523	448	391	349	313	285	261	241	224
0	105 560	167 800	2 500	1 670	1 250	1 000	833	713	625	500	416	357	312	277	250	227	208	192	178
1	83 694	133 220	1 970	1 320	987	790	658	563	493	395	329	282	247	219	197	179	164	152	140
2	66 358	105 530	1 570	1 045	783	627	522	448	392	313	261	224	196	174	157	142	130	120	112
3	52 624	83 640	1 240	826	620	496	413	354	310	248	207	177	155	138	124	113	103	95	88
4	41 738	66 370	990	661	495	396	330	283	247	198	167	141	123	110	99	90	82	76	70
5	33 088	52 630	786	524	393	314	262	225	196	157	131	112	98	87	78	71	65	60	56

4400 VOLTS DELIVERED

B & S NO.	COPPER	ALUMINUM	1 MILE	1½ MILES	2 MILES	2½ MILES	3 MILES	3½ MILES	4 MILES	5 MILES	6 MILES	7 MILES	8 MILES	9 MILES	10 MILES	11 MILES	12 MILES	13 MILES	14 MILES
	650 000	1 033 000	18 600	12 400	9 300	7 450	6 200	5 300	4 650	3 720	3 100	2 660	2 330	2 070	1 860	1 690	1 550	1 430	1 330
	600 000	954 000	17 100	11 400	8 550	6 850	5 700	4 880	4 270	3 420	2 850	2 440	2 140	1 900	1 710	1 550	1 430	1 320	1 220
	550 000	874 500	15 900	10 600	7 950	6 370	5 300	4 550	3 980	3 180	2 650	2 270	1 990	1 770	1 590	1 450	1 330	1 230	1 140
	500 000	795 000	14 300	9 530	7 150	5 720	4 770	4 080	3 570	2 870	2 380	2 050	1 780	1 590	1 430	1 300	1 190	1 100	1 020
	450 000	715 500	12 900	8 600	6 450	5 150	4 300	3 690	3 230	2 580	2 150	1 840	1 620	1 430	1 290	1 180	1 080	995	920
	400 000	636 000	11 500	7 650	5 750	4 600	3 830	3 290	2 880	2 300	1 920	1 640	1 440	1 280	1 150	1 050	960	887	825
	350 000	556 500	10 000	6 670	5 000	4 000	3 330	2 860	2 500	2 000	1 670	1 430	1 250	1 110	1 000	910	832	770	715
	300 000	477 000	8 590	5 720	4 290	3 440	2 860	2 450	2 150	1 720	1 430	1 230	1 070	950	858	780	715	660	613
	250 000	397 500	7 170	4 780	3 585	2 870	2 390	2 050	1 800	1 430	1 200	1 030	900	800	717	653	600	552	513
0000	211 600	336 420	6 050	4 030	3 025	2 420	2 020	1 730	1 510	1 210	1 010	865	755	673	605	550	505	467	433
000	167 772	266 800	4 820	3 220	2 410	1 930	1 610	1 380	1 210	965	805	688	603	535	482	438	402	371	345
00	133 079	211 950	3 790	2 530	1 895	1 520	1 260	1 080	950	758	632	543	475	422	379	345	317	292	271
0	105 560	167 800	3 030	2 020	1 515	1 220	1 010	867	758	607	506	433	379	337	303	276	253	233	217
1	83 694	133 220	2 390	1 590	1 195	955	795	683	598	478	398	341	299	266	239	217	199	183	171
2	66 358	105 530	1 900	1 270	950	760	633	542	475	380	317	271	237	211	190	173	158	146	136
3	52 624	83 640	1 500	1 000	750	600	500	428	375	300	250	214	188	167	150	136	125	116	107
4	41 738	66 370	1 200	800	600	480	400	342	300	240	200	172	150	133	120	109	100	92	86
5	33 088	52 630	950	633	475	380	318	272	237	190	158	136	119	106	95	87	80	73	65

The heating limitations may, for the shorter distances, particularly if insulated or concealed conductors are employed, necessitate the use of larger conductors, resulting in a correspondingly less transmission loss. In the case of insulated or concealed conductors, should the k.v.a. values fall near or to the left of the heavy line, consult Table XXV for insulated or Table XXIII for bare conductors. The reactance for the larger conductors may be excessive, particularly for 60-cycle service, producing excessive voltage drop. This may be obviated by installing two or more parallel circuits or using three-conductor cables. For single-phase circuits the k.v.a. will be one-half the table values.

TABLE XV—QUICK ESTIMATING TABLE

KILOVOLT-AMPERES, 3 PHASE, WHICH MAY BE DELIVERED AT THE FOLLOWING VOLTAGES OVER THE VARIOUS CONDUCTORS FOR THE DISTANCES STATED, BASED UPON THE FOLLOWING I^2R LOSS (EFFECT OF CHARGING CURRENT NEGLECTED)

	AT 25° C	AT 65° C
FOR LOAD POWER-FACTOR OF 100%	8.66% LOSS	10.0% LOSS
FOR LOAD POWER-FACTOR OF 80%	10.8% LOSS	12.5 LOSS

6000 VOLTS DELIVERED

B & S NO.	COPPER AREA IN CIRCULAR MILS	ALUMINUM AREA IN CIRCULAR MILS	1 MILE	1½ MILES	2 MILES	2½ MILES	3 MILES	3½ MILES	4 MILES	5 MILES	6 MILES	7 MILES	8 MILES	9 MILES	10 MILES	11 MILES	12 MILES	13 MILES	14 MILES
	650000	1033000	34600	23100	17300	13800	11500	9900	8650	6930	5780	4950	4320	3850	3460	3150	2890	2670	2470
	600000	954000	31800	21200	15900	12700	10600	9100	7950	6370	5300	4550	3980	3540	3180	2890	2650	2450	2270
	550000	874500	29500	19700	14700	11800	9850	8430	7370	5900	4920	4220	3690	3280	2950	2680	2460	2270	2110
	500000	795000	26600	17700	13300	10600	8860	7600	6670	5320	4450	3800	3330	2960	2660	2420	2220	2050	1900
	450000	715500	[illegible]	16000	[illegible]	9550	8000	6850	5900	4770	4000	3440	2950	2660	2390	2170	2000	1840	1720
	400000	636000	21300	14200	10700	8040	7120	6100	5340	4270	3561	3050	2670	2370	2130	1940	1780	1640	1530
	350000	556500	[illegible]	12400	9300	7440	6200	5310	4650	3720	3100	2660	2320	2070	1860	1690	1550	1430	1330
	300000	477000	[illegible]	[illegible]	[illegible]	6310	5310	4550	[illegible]	[illegible]	2650	2270	1990	1770	1590	1450	1330	1220	1130
	250000	397500	[illegible]	8910	6670	5330	4440	3810	3320	[illegible]	2220	1900	1670	1480	1330	1210	1110	1020	950
0000	211600	336420	[illegible]	7000	[illegible]	4500	3750	3210	2810	2250	1870	1610	1410	1250	1120	1020	937	866	800
000	167772	266800	8950	5970	4480	3580	2980	2560	2240	[illegible]	1490	1280	1120	995	895	814	746	689	640
00	133079	[illegible]	7060	[illegible]	[illegible]	2820	2350	2020	[illegible]	[illegible]	1180	1010	882	784	706	642	588	543	500
0	105560	167800	5620	3750	[illegible]	2250	1870	1610	[illegible]	[illegible]	937	803	703	625	562	515	468	433	400
1	83694	133220	4440	2960	[illegible]	1780	1480	1270	1110	890	741	634	555	494	444	404	370	342	317
2	66358	105530	3530	2350	[illegible]	1410	1170	1010	882	706	588	504	441	392	353	321	294	271	250
3	52624	83640	[illegible]	[illegible]	1390	[illegible]	930	[illegible]	697	558	465	398	348	310	279	253	232	215	200
4	41738	66370	2230	[illegible]	[illegible]	[illegible]	743	637	556	446	371	318	278	247	223	202	185	171	160
5	33088	52630	1770	[illegible]	884	708	590	505	442	354	295	252	221	196	177	161	146	136	126

6600 VOLTS DELIVERED

B & S NO.	COPPER AREA IN CIRCULAR MILS	ALUMINUM AREA IN CIRCULAR MILS	1 MILE	1½ MILES	2 MILES	2½ MILES	3 MILES	3½ MILES	4 MILES	5 MILES	6 MILES	7 MILES	8 MILES	9 MILES	10 MILES	11 MILES	12 MILES	13 MILES	14 MILES
	650000	1033000	41900	28000	20900	16800	14000	[illegible]	10500	8400	7000	6000	5250	4670	4190	3830	3500	3230	3000
	600000	954000	38500	25700	19300	15400	12800	[illegible]	9630	7700	6400	5500	4810	4270	3850	3500	3210	2960	2750
	550000	874500	[illegible]	23800	17800	14300	11900	10000	8430	7140	5950	5100	4460	3960	3570	3250	2980	2750	2550
	500000	795000	32300	21500	16100	12900	10800	[illegible]	[illegible]	6460	5400	4620	4030	3600	3230	2940	2690	2480	2310
	450000	715500	[illegible]	19400	14500	[illegible]	9700	[illegible]	7270	5820	4850	4150	3640	3230	2910	2640	2420	2240	2080
	400000	636000	[illegible]	17300	12900	10300	[illegible]	[illegible]	[illegible]	5180	4320	3700	3240	2880	2590	2360	2160	1990	1850
	350000	556500	22600	15000	11300	9040	[illegible]	6450	[illegible]	4520	3770	3220	2820	2510	2260	2050	1880	1740	1610
	300000	477000	[illegible]	[illegible]	9650	7720	[illegible]	6520	[illegible]	3860	3220	2760	2420	2150	1930	1760	1610	1480	1380
	250000	397500	[illegible]	[illegible]	8100	6480	5400	[illegible]	[illegible]	3240	2700	2310	2020	1800	1620	1470	1350	1240	1160
0000	211600	336420	[illegible]	[illegible]	[illegible]	[illegible]	4530	[illegible]	[illegible]	[illegible]	2260	1940	1700	1510	1360	1230	1130	1040	970
000	167772	266800	[illegible]	[illegible]	5400	4320	3600	[illegible]	[illegible]	[illegible]	1800	1540	1350	1200	1080	980	900	830	770
00	133079	[illegible]	[illegible]	[illegible]	4270	3420	2850	2440	[illegible]	[illegible]	1420	1220	1070	950	855	778	713	657	610
0	105560	167800	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1130	970	850	755	680	617	565	522	486
1	83694	133220	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1530	[illegible]	1070	895	767	672	597	538	490	448	413	385
2	66358	105530	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	854	710	610	533	477	427	390	356	329	306
3	52624	83640	[illegible]	2250	[illegible]	1350	[illegible]	965	[illegible]	676	565	483	422	376	338	307	282	260	241
4	41738	66370	[illegible]	1800	1350	1080	[illegible]	775	677	542	450	388	339	300	271	246	226	209	193
5	33088	52630	[illegible]	1420	[illegible]	860	[illegible]	612	535	428	356	306	268	238	214	195	178	165	151

10 000 VOLTS DELIVERED

B & S NO.	COPPER AREA IN CIRCULAR MILS	ALUMINUM AREA IN CIRCULAR MILS	6 MILES	7 MILES	8 MILES	9 MILES	10 MILES	11 MILES	12 MILES	13 MILES	14 MILES	15 MILES	16 MILES	18 MILES	20 MILES	22 MILES	24 MILES	26 MILES	28 MILES
	650000	1033000	16000	[illegible]	12100	10700	9620	8750	8020	7400	6870	6420	6000	5350	4820	4380	4020	3700	3440
	600000	954000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8050	[illegible]	6800	6320	5900	5530	4920	4420	4020	3680	3410	3160
	550000	874500	[illegible]	11700	[illegible]	[illegible]	8200	7450	6820	[illegible]	5850	5450	5120	4550	4100	3720	3410	3150	2920
	500000	795000	[illegible]	[illegible]	9250	[illegible]	7400	6720	6150	[illegible]	5280	4920	4620	4100	3700	3360	3090	2850	2640
	450000	715500	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6080	5560	5130	4770	4450	4170	3700	3340	3040	2780	2570	2390
	400000	636000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5390	4940	[illegible]	4240	3950	3710	3300	2970	2700	2470	2280	2120
	350000	556500	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4310	[illegible]	[illegible]	3440	3230	2870	2580	2350	2150	1990	1840
	300000	477000	[illegible]	[illegible]	[illegible]	4910	[illegible]	4020	[illegible]	3400	[illegible]	2950	2760	2460	2210	2010	1840	1700	1580
	250000	397500	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2640	2470	2310	2060	1850	1680	1540	1420	1320
0000	211600	336420	[illegible]	[illegible]	[illegible]	3470	[illegible]	[illegible]	[illegible]	[illegible]	2230	2080	1950	1740	1560	1420	1300	1200	1110
000	167772	266800	[illegible]	[illegible]	3110	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1780	[illegible]	[illegible]	1380	1240	1130	1040	957	890
00	133079	[illegible]	3270	[illegible]	[illegible]	[illegible]	1960	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1220	1090	980	891	817	754	700
0	105560	167800	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1300	[illegible]	[illegible]	[illegible]	976	868	781	710	651	601	558
1	83694	[illegible]	2060	[illegible]	[illegible]	1370	[illegible]	[illegible]	1030	[illegible]	882	823	771	686	617	561	514	474	441
2	66358	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	700	653	612	544	490	445	408	377	350
3	52624	83640	[illegible]	[illegible]	969	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	484	431	387	352	323	298	277
4	41738	66370	1030	[illegible]	[illegible]	688	[illegible]	[illegible]	[illegible]	[illegible]	442	413	387	344	309	281	258	238	221
5	33088	52630	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	447	409	[illegible]	351	327	307	273	245	223	204	189	175

11 000 VOLTS DELIVERED

B & S NO.	COPPER AREA IN CIRCULAR MILS	ALUMINUM AREA IN CIRCULAR MILS	6 MILES	7 MILES	8 MILES	9 MILES	10 MILES	11 MILES	12 MILES	13 MILES	14 MILES	15 MILES	16 MILES	18 MILES	20 MILES	22 MILES	24 MILES	26 MILES	28 MILES
	650000	1033000	9900	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9700	8920	8300	7750	7250	6450	5800	5270	4850	4450	4150
	600000	954000	11800	[illegible]	[illegible]	11900	[illegible]	[illegible]	8900	8230	7650	7150	6680	5950	5350	4870	4450	4120	3820
	550000	874500	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7080	6600	6200	5500	4960	4500	4120	3810	3540
	500000	795000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6900	6400	5980	5600	5000	4480	4080	3720	3450	3200
	450000	715500	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6200	5770	5380	5050	4470	4030	3670	3370	3100	2880
	400000	636000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5550	5150	4800	4500	4000	3600	3270	3000	2780	2570
	350000	556500	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5680	[illegible]	4830	4470	4180	3910	3480	3130	2840	2620	2410	2230
	300000	477000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4870	[illegible]	4120	3830	3560	3350	2990	2670	2430	2230	2060	1910
	250000	397500	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4070	[illegible]	3440	3200	2990	2800	2490	2240	2030	1870	1720	1600
0000	211600	336420	[illegible]	5400	[illegible]	[illegible]	[illegible]	3440	[illegible]	2910	2700	2530	2360	2100	1890	1720	1570	1450	1350
000	167772	[illegible]	5020	4300	[illegible]	[illegible]	3010	[illegible]	[illegible]	2310	2150	2010	1880	1670	1500	1370	1250	1150	1070
00	133079	[illegible]	[illegible]	3390	[illegible]	[illegible]	[illegible]	2150	1980	1820	1700	1580	1480	1320	1180	1070	990	910	850
0	105560	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	890	[illegible]	[illegible]	1450	1350	1260	1180	1050	945	860	787	725	675
1	83694	133220	2400	[illegible]	[illegible]	[illegible]	[illegible]	1360	[illegible]	[illegible]	1070	1000	935	835	747	680	622	575	535
2	66358	105530	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1080	990	910	845	790	740	660	592	540	495	455	422
3	52624	83640	[illegible]	1340	[illegible]	[illegible]	940	850	785	[illegible]	670	627	585	520	469	425	392	360	335
4	41738	[illegible]	[illegible]	[illegible]	[illegible]	876	750	685	625	578	537	503	471	418	376	342	312	289	268
5	33088	[illegible]	990	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	457	424	395	371	330	296	270	247	228	212

The heating limitations may, for the shorter distances, particularly if insulated or concealed conductors are employed, necessitate the use of larger conductors, resulting in a correspondingly less transmission loss. In the case of insulated or concealed conductors, should the k.v.a. values fall near or to the left of the heavy line, consult Table XXV for insulated or Table XXIII for bare conductors. The reactance for the larger conductors may be excessive, particularly for 60-cycle service, producing excessive voltage drop. This may be obviated by installing two or more parallel circuits or using three-conductor cables. For single-phase circuits the k.v.a. will be one-half the table values.

TABLE XVI—QUICK ESTIMATING TABLE

CONDUCTORS

KILOVOLT-AMPERES, 3 PHASE, WHICH MAY BE DELIVERED AT THE FOLLOWING VOLTAGES OVER THE VARIOUS CONDUCTORS FOR THE DISTANCES STATED. BASED UPON THE FOLLOWING I^2R LOSS (EFFECT OF CHARGING CURRENT NEGLECTED)

	AT 25° C	AT 65° C
FOR LOAD POWER-FACTOR OF 100%	8.66% LOSS	10.0% LOSS
FOR LOAD POWER-FACTOR OF 80%	10.8% LOSS	12.5 LOSS

12 000 VOLTS DELIVERED

B & S NO.	COPPER AREA IN CIRCULAR MILS	ALUMINUM AREA IN CIRCULAR MILS	6 MILES	7 MILES	8 MILES	9 MILES	10 MILES	11 MILES	12 MILES	13 MILES	14 MILES	15 MILES	16 MILES	18 MILES	20 MILES	22 MILES	24 MILES	26 MILES	28 MILES
	650000	1033000	23100	19800	17300	15400	13900	12600	11600	10700	9900	9250	8650	7700	6950	6300	5800	5350	4950
	600000	954000	21200	18200	15900	14200	12700	11600	10600	9800	9100	8500	7950	7100	6350	5800	5300	4900	4550
	550000	874500	19700	16900	14800	13200	11800	10800	9850	9100	8450	7900	7400	6600	5900	5400	4920	4550	4220
	500000	795000	17800	15300	13300	11900	10700	9700	8900	8200	7600	7100	6650	5900	5350	4850	4450	4100	3800
	450000	715500	16000	13700	12000	10600	9600	8600	8000	7380	6850	6400	6000	5300	4800	4300	4000	3690	3420
	400000	636000	14200	12200	10700	9490	8540	7770	7120	6570	6100	5700	5340	4750	4270	3880	3560	3290	3050
	350000	556500	12400	10600	9300	8270	7440	6760	6200	5720	5300	4960	4650	4130	3720	3380	3100	2860	2660
	300000	477000	10600	9100	7960	7080	6370	5790	5310	4900	4550	4250	3980	3540	3190	2890	2650	2450	2270
	250000	397500	8900	7620	6670	5920	5330	4850	4440	4100	3810	3550	3330	2960	2670	2420	2220	2050	1900
0000	211600	336420	7500	6430	5620	5000	4500	4090	3750	3460	3210	3000	2810	2500	2250	2040	1870	1730	1610
000	167772	266800	5970	5120	4480	3980	3580	3250	2990	2750	2560	2390	2240	1990	1791	1630	1490	1380	1280
00	133079	211950	4710	4033	3530	3140	2820	2560	2350	2170	2010	1880	1760	1570	1410	1280	1180	1090	1010
0	105560	167800	3750	3210	2810	2500	2250	2050	1870	1730	1610	1500	1410	1250	1120	1020	930	865	803
1	83694	133220	2960	2540	2220	1970	1780	1610	1480	1370	1270	1180	1110	990	890	810	740	683	635
2	66358	105530	2350	2010	1760	1570	1410	1280	1170	1090	1010	940	880	780	700	640	590	543	504
3	52624	83640	1860	1590	1390	1240	1110	1010	930	860	790	740	700	620	560	510	460	430	400
4	41738	66370	1490	1270	1110	990	890	810	740	680	640	590	560	490	440	400	370	343	318
5	33088	52630	1180	1010	884	780	710	640	590	540	500	472	440	390	350	320	295	272	252

13 200 VOLTS DELIVERED

B & S NO.	COPPER	ALUMINUM	6 MILES	7 MILES	8 MILES	9 MILES	10 MILES	11 MILES	12 MILES	13 MILES	14 MILES	15 MILES	16 MILES	18 MILES	20 MILES	22 MILES	24 MILES	26 MILES	28 MILES
	650000	1033000	27900	24000	20900	18600	16700	15200	14000	12700	12000	11200	10400	9300	8370	7600	7000	6450	6000
	600000	954000	25700	22000	19300	[illegible]	15400	14000	12800	11800	11000	10300	9650	8550	7700	7000	6400	5920	5500
	550000	874500	23900	20400	17900	[illegible]	14300	13000	11900	11000	10200	9550	8950	7950	[illegible]	6500	5950	[illegible]	5100
	500000	795000	21500	18500	16100	14300	12900	11700	10700	9920	9220	8600	8050	[illegible]	6450	5850	5350	4960	4610
	450000	715500	19300	16600	14500	12900	11600	10600	9700	8930	8280	7750	7250	[illegible]	5800	5300	4850	4460	[illegible]
	400000	636000	17300	14800	12900	11500	10300	[illegible]	8650	8000	7400	6900	6450	5700	[illegible]	[illegible]	4320	4000	3700
	350000	556500	15100	12900	11300	10000	9020	8200	7520	6950	6450	6020	5650	5000	4510	[illegible]	3760	3470	3220
	300000	477000	12900	[illegible]	9650	8570	7720	[illegible]	6430	5930	5520	5150	4820	4280	3860	3510	[illegible]	2960	2760
	250000	397500	10800	9250	8080	7180	6450	5870	5380	4960	4620	4300	4040	3600	3220	2930	2700	2480	2310
0000	211600	336420	9100	7800	6850	6070	5450	4970	4550	4200	3900	3640	3420	3030	2720	2480	2270	[illegible]	[illegible]
000	167772	266800	7220	6200	5420	4820	4330	3940	3620	3330	3100	2890	2710	[illegible]	2160	[illegible]	[illegible]	[illegible]	[illegible]
00	133079	211950	5700	4900	4280	3800	3420	3110	2850	2630	2450	2280	2140	1900	[illegible]	1550	1420	[illegible]	1220
0	105560	167800	4550	3900	3410	3030	2730	2480	2270	2100	1950	1820	1700	[illegible]	1360	1240	[illegible]	1050	975
1	83694	133220	3590	3070	[illegible]	[illegible]	2150	1960	1800	1660	1540	1430	1340	1200	[illegible]	980	900	830	770
2	66358	105530	2850	2440	[illegible]	[illegible]	[illegible]	1560	1430	1320	1220	[illegible]	1070	950	850	780	[illegible]	660	610
3	52624	83640	2250	1930	1680	[illegible]	[illegible]	1220	1120	[illegible]	960	900	840	750	670	[illegible]	560	510	480
4	41738	66370	1800	1550	1360	[illegible]	1080	985	900	830	770	720	680	600	540	490	450	420	390
5	33088	52630	1420	1220	1070	950	850	[illegible]	710	660	610	570	530	470	430	390	360	330	300

15 000 VOLTS DELIVERED

B & S NO.	COPPER	ALUMINUM	6 MILES	7 MILES	8 MILES	9 MILES	10 MILES	11 MILES	12 MILES	13 MILES	14 MILES	15 MILES	16 MILES	18 MILES	20 MILES	22 MILES	24 MILES	26 MILES	28 MILES
	650000	1033000	36000	31000	27000	24000	21600	19800	18000	16600	15400	14400	13500	12000	10800	9900	9000	8300	7700
	600000	954000	33200	28500	24900	22200	19900	18200	16600	15300	14200	13300	12400	11100	9950	9100	8300	7650	7100
	550000	874500	30600	26300	23000	20500	18400	16700	15300	14100	13100	12300	11500	10200	9200	8350	7650	7050	6550
	500000	795000	27800	23900	20800	18600	16700	15200	13900	12800	11900	11100	10400	9300	8350	7600	6950	6400	5950
	450000	715500	25000	21400	18700	16700	15000	13600	12500	11500	10700	10000	9350	8350	7500	6800	6250	5750	5350
	400000	636000	22200	19000	16700	14800	13300	12100	11100	10200	9540	8900	8340	7420	6670	6070	5560	5130	4770
	350000	556500	19400	16600	14500	12900	11600	10600	9690	8940	8300	7750	7260	6460	5810	5280	4840	4470	4150
	300000	477000	16600	14200	12400	[illegible]	9960	9050	8290	7660	7100	6640	6220	5530	5000	4520	4150	3830	3550
	250000	397500	13900	11900	10400	[illegible]	8330	7570	6940	[illegible]	5950	5560	5210	4630	[illegible]	3790	3470	3200	2980
0000	211600	336420	11700	10000	8790	6220	7030	6390	5860	[illegible]	5020	4680	4390	3900	3510	3200	2930	2700	2510
000	167772	266800	9330	8000	7000	4900	5600	5090	4660	4300	4000	3730	3500	[illegible]	2800	2540	2330	[illegible]	2000
00	133079	211950	7350	6300	5510	[illegible]	4410	4010	[illegible]	3390	[illegible]	2940	2760	2450	2210	2000	1840	1700	1570
0	105560	167800	5860	5000	4390	3090	3510	3190	2930	2700	2510	2340	2200	1950	1760	1600	1460	1350	1250
1	83694	133220	4630	3970	3470	2450	2780	2520	2310	2140	1980	1850	1740	1540	1390	1260	1160	1070	990
2	66358	105530	3670	3150	2760	1940	2210	2000	1840	[illegible]	1570	1470	1380	1220	1100	1000	920	850	780
3	52624	83640	2910	2490	[illegible]	[illegible]	[illegible]	1590	1450	1340	1240	1160	1090	970	870	790	730	670	620
4	41738	66370	2320	1990	1740	1230	1390	[illegible]	[illegible]	1070	990	930	870	774	690	630	580	530	490
5	33088	52630	1840	1580	1380	970	1110	1000	[illegible]	850	[illegible]	730	690	614	430	500	460	420	390

16 500 VOLTS DELIVERED

B & S NO.	COPPER	ALUMINUM	6 MILES	7 MILES	8 MILES	9 MILES	10 MILES	11 MILES	12 MILES	13 MILES	14 MILES	15 MILES	16 MILES	18 MILES	20 MILES	22 MILES	24 MILES	26 MILES	28 MILES
	650000	1033000	45400	38900	34000	30300	27200	24700	22700	21000	19500	18200	17000	15100	13600	12300	11300	10500	9750
	600000	954000	40200	34500	30200	26800	24100	21900	20100	18600	17200	16100	15100	13400	12000	10900	10000	9300	8600
	550000	874500	37200	31900	27900	24800	22300	20300	18600	17200	15900	14800	13900	12400	11100	10100	9300	8600	7950
	500000	795000	33700	28900	25300	22500	20200	18300	16800	15500	14400	13500	12600	11200	10100	9150	8400	7750	7200
	450000	715500	30400	26000	22800	20300	18200	16600	15200	14000	13000	12100	11400	10100	9100	8300	7600	7000	6500
	400000	636000	27000	23100	20200	18000	16200	14700	13500	2400	11600	10800	10100	9000	8100	7350	6750	6200	5800
	350000	556500	23700	20300	17700	5800	14200	12900	11800	10900	10200	9480	8850	7900	7100	6450	5900	5450	5100
	300000	477000	20200	17200	15100	3400	12100	11000	10100	9300	8650	8060	7550	6700	6050	5500	5050	4650	4320
	250000	397500	16800	14400	12600	11200	10100	9200	8450	7780	7220	6720	6300	5600	5050	4600	4220	3890	3610
0000	211600	336420	14200	12200	11700	9500	8520	7770	7100	6560	6080	5700	5850	4750	4260	3880	3550	3280	3040
000	167772	266800	11300	9700	8500	7550	6780	6170	5670	5220	4860	4530	4250	3770	3390	3080	2830	2610	2430
00	133079	211950	8920	7650	6700	5950	5370	4870	4460	4120	3830	3580	3350	2970	2670	2430	2230	2060	1910
0	105560	167800	7100	6100	5320	4720	4260	3860	3540	3270	3040	2840	2660	2360	2130	1930	1770	1630	1520
1	83694	133220	5620	4820	4220	3750	3370	3070	2810	2590	2410	2250	2110	1870	1680	1530	1400	1290	1200
2	66358	105530	4450	3820	3340	2970	2670	2430	2230	2060	1910	1780	1670	1480	1330	1210	1110	1030	950
3	52624	83640	3540	3030	2650	2360	2120	1930	1760	1630	1510	1410	1320	1180	1060	960	880	810	750
4	41738	66370	2820	2420	2120	1880	1690	1530	1410	1300	1210	1130	1060	940	840	760	700	650	600
5	33088	52630	2220	1900	1670	1480	1330	1210	1120	1020	950	890	830	740	670	600	560	510	480

The heating limitations may, for the shorter distances, particularly if insulated or concealed conductors are employed, necessitate the use of larger conductors, resulting in a correspondingly less transmission loss. In the case of insulated or concealed conductors, should the k.v.a. values fall near or to the left of the heavy line, consult Table XXV for insulated or Table XXIII for bare conductors. The reactance for the larger conductors may be excessive, particularly for 60-cycle service, producing excessive voltage drop. This may be obviated by installing two or more parallel circuits or using three-conductor cables. For single-phase circuits the k.v.a. will be one-half the table values.

TABLE XVII—QUICK ESTIMATING TABLE

KILOVOLT-AMPERES, 3 PHASE, WHICH MAY BE DELIVERED AT THE FOLLOWING VOLTAGES OVER THE VARIOUS CONDUCTORS FOR THE DISTANCES STATED. BASED UPON THE FOLLOWING I^2R LOSS (EFFECT OF CHARGING CURRENT NEGLECTED)

	AT 25° C	AT 65° C
FOR LOAD POWER-FACTOR OF 100%	8.66% LOSS	10.0% LOSS
FOR LOAD POWER-FACTOR OF 80%	10.8% LOSS	12.5 LOSS

CONDUCTORS: B & S NO.; COPPER AREA IN CIRCULAR MILS; ALUMINUM AREA IN CIRCULAR MILS

20 000 VOLTS DELIVERED

B & S NO.	COPPER	ALUMINUM	7 MILES	8 MILES	9 MILES	10 MILES	11 MILES	12 MILES	13 MILES	14 MILES	15 MILES	16 MILES	18 MILES	20 MILES	22 MILES	24 MILES	26 MILES	28 MILES	30 MILES
	650 000	1 033 000	55 000	47 200	42 700	38 500	34 900	32 000	29 600	27 500	25 700	23 600	21 300	19 200	17 400	16 000	14 800	13 400	12 800
	600 000	954 000	50 500	44 200	39 400	35 400	32 200	29 500	27 200	25 300	23 600	22 100	19 700	17 700	16 100	14 700	13 600	12 700	11 800
	550 000	874 500	46 800	41 000	36 500	32 800	29 800	27 300	25 200	23 400	21 800	20 500	18 200	16 400	14 900	13 600	12 600	11 700	10 900
	500 000	795 000	42 500	37 000	33 000	29 700	27 000	24 700	22 800	21 200	19 800	18 500	16 500	14 800	13 500	12 300	11 400	10 600	9 900
	450 000	715 500	38 200	33 400	29 600	26 600	24 300	22 200	20 500	19 000	17 800	16 700	14 800	13 300	12 100	11 100	10 200	9 500	8 900
	400 000	636 000	33 900	29 600	26 400	23 700	21 600	19 800	18 200	16 900	15 800	14 800	13 200	11 800	10 800	9 890	9 130	8 480	7 910
	350 000	556 500	29 500	25 800	23 000	20 700	18 800	17 200	15 900	14 700	13 800	12 900	11 500	10 300	9 400	8 610	7 950	7 380	6 890
	300 000	477 000	25 300	22 100	19 700	17 700	16 100	14 700	13 600	12 600	11 800	11 000	9 830	8 850	8 050	7 370	6 810	6 320	5 900
	250 000	397 500	21 100	18 500	16 400	14 800	13 400	12 300	11 400	10 600	9 880	9 260	8 230	7 410	6 730	6 170	5 700	5 290	4 940
0000	211 600	336 420	17 800	15 600	13 900	12 500	11 300	10 400	9 610	8 930	8 330	7 810	6 940	6 250	5 680	5 210	4 810	4 460	4 170
000	167 772	266 800	14 200	12 400	11 000	9 950	9 040	8 280	7 650	7 110	6 630	6 220	5 530	4 970	4 520	4 150	3 830	3 550	3 310
00	133 079	211 950	11 200	9 800	8 710	7 840	7 130	6 530	6 030	5 600	5 230	4 900	4 360	3 920	3 560	3 270	3 010	2 800	2 610
0	105 560	167 800	8 930	7 810	6 940	6 250	5 680	5 210	4 810	4 460	4 170	3 910	3 470	3 120	2 840	2 600	2 400	2 230	2 080
1	83 694	133 220	7 050	6 170	5 490	4 940	4 490	4 110	3 810	3 530	3 290	3 090	2 740	2 470	2 240	2 060	1 900	1 760	1 640
2	66 358	105 530	5 600	4 900	4 360	3 920	3 560	3 270	3 020	2 800	2 610	2 450	2 180	1 960	1 780	1 630	1 510	1 400	1 310
3	52 624	83 640	4 430	3 870	3 440	3 100	2 820	2 580	2 380	2 210	2 070	1 940	1 720	1 550	1 410	1 290	1 190	1 110	1 030
4	41 738	66 370	3 540	3 100	2 750	2 480	2 250	2 060	1 900	1 770	1 650	1 550	1 380	1 240	1 120	1 030	950	884	820
5	33 088	52 630	2 810	2 460	2 180	1 960	1 790	1 640	1 510	1 400	1 310	1 230	1 090	980	890	820	750	700	650

22 000 VOLTS DELIVERED

B & S NO.	COPPER	ALUMINUM	7 MILES	8 MILES	9 MILES	10 MILES	11 MILES	12 MILES	13 MILES	14 MILES	15 MILES	16 MILES	18 MILES	20 MILES	22 MILES	24 MILES	26 MILES	28 MILES	30 MILES
	650 000	1 033 000	66 500	58 200	51 800	46 600	42 200	38 800	35 800	33 300	31 000	29 100	25 900	23 300	21 100	19 400	17 900	16 600	15 500
	600 000	954 000	61 200	53 500	47 600	42 800	38 900	35 600	32 900	30 600	27 500	26 700	23 800	21 400	19 400	17 800	16 400	15 300	13 700
	550 000	874 500	56 800	49 600	44 200	39 700	36 100	33 100	30 500	28 400	26 600	24 800	22 100	19 800	18 000	16 500	15 200	14 200	13 200
	500 000	795 000	51 300	44 800	40 000	35 900	32 600	29 900	27 600	25 700	23 900	22 400	20 000	17 900	16 300	14 900	13 800	12 800	11 900
	450 000	715 500	46 000	40 200	35 800	32 200	29 300	26 900	24 800	23 000	21 500	20 100	17 900	16 100	14 600	13 400	12 400	11 500	10 700
	400 000	636 000	41 200	36 000	32 000	28 800	26 200	24 000	22 200	20 600	19 200	18 000	16 000	14 400	13 100	12 000	11 100	10 300	9 600
	350 000	556 500	35 800	31 400	27 900	25 100	22 800	20 900	19 300	17 900	16 700	15 700	13 900	12 550	11 400	10 400	9 650	8 950	8 350
	300 000	477 000	30 600	26 700	23 800	21 400	19 400	17 800	16 500	15 300	14 200	13 300	11 900	10 700	9 700	8 900	8 250	7 650	7 100
	250 000	397 500	25 600	22 400	19 900	17 900	16 300	14 900	13 800	12 800	12 000	11 200	9 950	8 950	8 150	7 450	6 900	6 400	6 000
0000	211 600	336 420	21 500	18 900	16 800	15 100	13 700	12 600	11 600	10 800	10 100	9 450	8 400	7 550	6 850	6 300	5 800	5 400	5 050
000	167 772	266 800	17 300	15 100	13 400	12 100	11 000	10 100	9 300	8 650	8 080	7 550	6 700	6 050	5 500	5 050	4 650	4 320	4 040
00	133 079	211 950	13 600	11 800	10 600	9 500	8 650	7 920	7 300	6 780	6 330	5 900	5 300	4 750	4 320	3 960	3 650	3 390	3 160
0	105 560	167 800	10 800	9 450	8 380	7 550	6 860	6 300	5 820	5 400	5 030	4 720	4 190	3 770	3 430	3 150	2 910	2 700	2 510
1	83 694	133 220	8 520	7 480	6 650	5 970	5 420	4 980	4 600	4 270	3 980	3 740	3 320	2 980	2 710	2 490	2 300	2 130	1 980
2	66 358	105 530	6 780	5 950	5 280	4 750	4 320	3 960	3 660	3 400	3 180	2 970	2 640	2 370	2 160	1 980	1 830	1 700	1 590
3	52 624	83 640	5 360	4 680	4 170	3 750	3 410	3 130	2 890	2 680	2 500	2 340	2 080	1 870	1 700	1 560	1 440	1 340	1 250
4	41 738	66 370	4 300	3 770	3 340	3 010	2 740	2 510	2 320	2 150	2 010	1 880	1 670	1 500	1 370	1 250	1 160	1 070	1 000
5	33 088	52 630	3 390	2 970	2 640	2 370	2 160	1 980	1 820	1 690	1 580	1 480	1 320	1 180	1 080	990	910	840	790

30 000 VOLTS DELIVERED

B & S NO.	COPPER	ALUMINUM	12 MILES	14 MILES	16 MILES	18 MILES	20 MILES	22 MILES	24 MILES	26 MILES	28 MILES	30 MILES	32 MILES	36 MILES	40 MILES	44 MILES	48 MILES	52 MILES	56 MILES
	650 000	1 033 000	72 200	62 000	54 200	48 200	43 200	39 400	36 100	33 300	30 900	28 900	27 100	24 100	21 600	19 700	18 000	16 600	15 400
	600 000	954 000	66 200	56 800	49 700	44 200	39 800	36 200	33 200	30 500	28 400	26 500	24 800	22 100	19 900	18 100	16 600	15 200	14 200
	550 000	874 500	61 500	52 800	46 200	41 000	36 900	33 500	30 800	28 400	26 400	24 700	23 100	20 500	18 400	16 700	15 400	14 200	13 200
	500 000	795 000	55 600	47 800	41 800	37 100	33 400	30 400	27 900	25 700	23 900	22 300	20 900	18 500	16 700	15 200	13 900	12 800	11 900
	450 000	715 500	50 000	42 800	37 500	33 400	30 000	27 300	25 100	23 100	21 500	20 000	18 700	[illegible]	15 000	13 600	12 500	11 500	10 700
	400 000	636 000	44 500	38 100	33 400	29 700	26 700	24 300	22 200	20 500	19 100	17 800	16 700	14 800	13 300	12 100	11 100	10 200	9 540
	350 000	556 500	38 700	33 200	29 100	25 800	23 200	21 100	19 400	17 900	16 600	15 500	14 500	12 900	11 600	10 600	9 690	8 940	8 300
	300 000	477 000	33 200	28 400	24 900	22 100	19 900	18 100	16 600	15 300	14 200	13 200	12 400	11 000	9 950	9 050	8 290	7 660	7 100
	250 000	397 500	27 800	23 800	20 800	18 500	16 700	15 100	13 900	12 800	11 900	11 100	10 400	9 260	8 330	7 570	6 940	6 400	5 950
0000	211 600	336 420	23 400	20 100	17 600	15 600	14 100	12 800	11 700	10 800	10 000	9 370	8 790	7 810	7 030	6 390	5 860	5 410	5 020
000	167 772	266 800	18 600	16 000	14 000	12 400	11 200	10 200	9 330	8 610	8 000	7 460	7 000	6 220	5 600	5 090	4 660	4 300	4 000
00	133 079	211 950	14 700	12 600	11 030	9 800	8 820	8 020	7 350	6 790	6 300	5 880	5 510	4 900	4 410	4 010	3 670	3 390	3 150
0	105 560	167 800	11 700	10 000	8 800	7 810	7 030	6 390	5 860	5 400	5 020	4 690	4 390	3 910	3 510	3 190	2 930	2 700	2 510
1	83 694	133 220	9 260	7 940	6 940	6 170	5 550	5 050	4 630	4 270	3 970	3 700	3 470	3 090	2 780	2 520	2 310	2 140	1 980
2	66 358	105 530	7 350	6 300	5 510	4 900	4 410	4 010	3 670	3 390	3 150	2 940	2 760	2 450	2 210	2 000	1 840	1 690	1 570
3	52 624	83 640	5 810	4 980	4 360	3 880	3 490	3 170	29[illegible]0	2 680	2 490	2 330	2 180	1 940	1 740	1 580	1 450	1 340	1 240
4	41 738	66 370	4 640	3 980	3 480	3 100	2 790	2 530	2 320	2 140	1 990	1 860	1 740	1 550	1 390	1 270	1 160	1 070	990
5	33 088	52 630	3 681	3 160	2 760	2 450	2 210	2 010	1 840	1 700	1 580	1 470	1 380	1 230	1 100	1 000	920	850	790

33 000 VOLTS DELIVERED

B & S NO.	COPPER	ALUMINUM	12 MILES	14 MILES	16 MILES	18 MILES	20 MILES	22 MILES	24 MILES	26 MILES	28 MILES	30 MILES	32 MILES	36 MILES	40 MILES	44 MILES	48 MILES	52 MILES	56 MILES
	650 000	1 033 000	87 200	74 700	65 300	58 200	52 200	47 600	43 700	40 200	37 400	34 800	32 650	[illegible]	26 100	23 800	21 800	20 100	18 700
	600 000	954 000	80 200	68 800	60 200	53 600	48 200	43 800	40 200	37 100	34 400	32 100	30 100	26 800	24 100	21 900	20 100	18 500	17 200
	550 000	874 500	75 500	64 800	56 700	50 400	45 300	41 200	37 700	34 800	32 400	30 300	28 300	25 200	22 600	20 600	18 800	17 400	16 200
	500 000	795 000	67 300	57 800	50 600	45 000	40 400	36 800	33 700	31 100	28 900	27 000	25 300	22 500	20 200	18 400	16 800	15 500	14 400
	450 000	715 500	60 400	51 800	45 300	40 200	36 300	33 000	30 200	27 900	25 900	24 100	22 600	20 100	18 100	16 500	15 100	13 900	12 900
	400 000	636 000	54 000	46 300	40 600	36 000	32 400	29 500	27 000	25 000	23 200	21 600	20 300	18 000	16 200	14 700	13 500	12 500	11 600
	350 000	556 500	47 000	40 300	35 300	31 400	28 200	25 700	23 500	21 700	20 200	18 800	17 600	15 700	14 100	12 800	11 700	10 800	10 100
	300 000	477 000	40 200	34 500	30 200	26 900	24 100	21 900	20 100	18 600	17 300	16 100	15 100	13 400	12 000	10 900	10 000	9 300	8 650
	250 000	397 500	33 700	28 800	25 200	22 400	20 200	18 300	16 800	15 500	14 400	13 400	12 600	11 200	10 100	9 150	8 400	7 750	7 200
0000	211 600	336 420	28 300	24 300	21 200	18 900	17 000	15 400	14 200	13 100	12 200	11 400	10 600	9 450	8 500	7 700	7 100	6 550	6 100
000	167 772	266 800	22 600	19 300	16 900	15 000	13 500	12 300	11 300	10 500	9 680	9 050	8 450	7 500	6 750	6 150	5 650	5 200	4 840
00	133 079	211 950	17 800	15 200	13 300	11 800	10 700	9 700	8 900	8 220	7 620	7 120	6 650	5 900	5 350	4 850	4 450	4 110	3 810
0	105 560	167 800	14 200	12 200	10 600	9 460	8 520	7 750	7 100	6 550	6 080	5 680	5 300	4 730	4 260	3 870	3 550	3 270	3 040
1	83 694	133 220	11 200	9 600	8 400	7 480	6 720	6 120	5 600	5 180	4 820	4 500	4 200	3 740	3 360	3 060	2 800	2 590	2 410
2	66 358	105 530	8 900	7 620	6 670	5 920	5 330	4 850	4 450	4 100	3 810	3 560	3 340	2 960	2 670	2 430	2 230	2 050	1 910
3	52 624	83 640	7 050	6 050	5 300	4 700	4 230	3 850	3 520	3 250	3 020	2 820	2 650	2 350	2 110	1 920	1 760	1 620	1 510
4	41 738	66 370	5 650	4 850	4 230	3 760	3 390	3 080	2 820	2 610	2 420	2 260	2 110	1 880	1 690	1 540	1 410	1 300	1 210
5	33 088	52 630	4 430	3 800	3 330	2 960	2 670	2 420	2 220	2 050	1 900	1 770	1 660	1 480	1 330	1 210	1 110	1 020	950

The heating limitations may, for the shorter distances, particularly if insulated or concealed conductors are employed, necessitate the use of larger conductors, resulting in a correspondingly less transmission loss. In the case of insulated or concealed conductors, should the k.v.a. values fall near or to the left of the heavy line, consult Table XXV for insulated or Table XXIII for bare conductors. The reactance for the larger conductors may be excessive, particularly for 60-cycle service, producing excessive voltage drop. This may be obviated by installing two or more parallel circuits or using three-conductor cables. For single-phase circuits the k.v.a. will be one-half the table values.

TABLE XVIII—QUICK ESTIMATING TABLE

CONDUCTORS

KILOVOLT-AMPERES, 3 PHASE, WHICH MAY BE DELIVERED AT THE FOLLOWING VOLTAGES OVER THE VARIOUS CONDUCTORS FOR THE DISTANCES STATED. BASED UPON THE FOLLOWING I^2R LOSS (EFFECT OF CHARGING CURRENT NEGLECTED)

	AT 25° C	AT 65° C
FOR LOAD POWER-FACTOR OF 100%	8.66% LOSS	10.0% LOSS
FOR LOAD POWER-FACTOR OF 80%	10.8% LOSS	12.5 LOSS

40 000 VOLTS DELIVERED

B & S NO.	COPPER AREA IN CIRCULAR MILS	ALUMINUM AREA IN CIRCULAR MILS	14 MILES	16 MILES	18 MILES	20 MILES	22 MILES	24 MILES	26 MILES	28 MILES	30 MILES	32 MILES	36 MILES	40 MILES	44 MILES	48 MILES	52 MILES	56 MILES	60 MILES
	650000	1033000	110000	96000	85300	76800	70000	64200	59000	55000	51300	48000	42600	38400	35000	32100	29500	27500	25600
	600000	954000	101000	88700	78800	70800	64500	59000	54500	50700	47300	44300	39400	35400	32200	29500	27200	25300	23600
	550000	874500	93800	82000	73000	65500	59700	54700	50500	46800	43700	41000	36500	32700	29800	27300	25200	23400	21800
	500000	795000	84600	74000	66000	59200	54000	49400	45600	42300	39500	37000	33000	29600	27000	24700	22800	21100	19700
	450000	715500	76300	66700	59200	53500	48500	44500	41000	38100	35600	33300	29600	26700	24200	22200	20500	19000	17800
	400000	636000	67800	59300	52700	47500	43100	39500	36500	33900	31600	29700	26400	23700	21600	19800	18200	16900	15800
	350000	556500	59000	51700	45900	41300	37600	34400	31800	29500	27500	25800	23000	20700	18800	17200	15900	14700	13800
	300000	477000	50600	44200	39300	35400	32200	29500	27200	25300	23600	22100	19700	17700	16100	14700	13600	12600	11800
	250000	397500	42300	37000	32900	29600	26900	24700	22800	21100	19700	18500	16400	14800	13500	12300	11400	10600	9880
0000	211600	336420	35700	31200	27800	25000	22700	20800	19200	17800	16700	15600	13900	12500	11400	10400	9610	8930	8330
000	167772	266800	28400	24800	22100	19900	18100	16600	15300	14200	13200	12400	11000	9950	9040	8230	7650	7110	6630
00	133079	211950	22400	19600	17400	15700	14200	13100	12100	11200	10400	9800	8710	7840	7130	6530	6030	5600	5230
0	105560	167800	17800	15600	13900	12500	11300	10400	9620	8930	8330	7810	6940	6250	5680	5210	4810	4460	4170
1	83694	133220	14100	12300	10900	9880	8980	8230	7590	7050	6580	6170	5490	4940	4490	4110	3800	3530	3290
2	66358	105530	11200	9800	8710	7840	7130	6540	6030	5600	5230	4900	4360	3920	3560	3270	3020	2800	2610
3	52624	83640	8860	7750	6880	6200	5640	5170	4770	4430	4130	3870	3440	3100	2820	2580	2380	2210	2070
4	41738	66370	7070	6190	5500	4950	4500	4130	3810	3540	3300	3090	2750	2480	2250	2060	1910	1770	1650
5	33088	52630	5610	4910	4370	3930	3570	3280	3020	2810	2620	2460	2180	1960	1790	1640	1510	1400	1310

44 000 VOLTS DELIVERED

B & S NO.	COPPER	ALUMINUM	14 MILES	16 MILES	18 MILES	20 MILES	22 MILES	24 MILES	26 MILES	28 MILES	30 MILES	32 MILES	36 MILES	40 MILES	44 MILES	48 MILES	52 MILES	56 MILES	60 MILES
	650000	1033000	133000	116000	103000	93000	84500	77500	71500	66500	62000	58000	51500	46500	42200	38700	35700	33200	31000
	600000	954000	122000	107000	95000	85500	77800	71500	66000	61200	57200	53500	47500	42700	38900	35700	33000	30600	28600
	550000	874500	113000	99000	88000	79200	72000	66000	61000	56500	52800	49500	44000	39600	36000	33000	30500	28200	26400
	500000	795000	102000	89700	79700	71800	65300	59800	55200	51300	47800	44800	39800	35900	32600	29800	27600	25600	23900
	450000	715500	92200	80700	71600	64500	58700	53800	49700	46200	43000	40300	35800	32200	29300	26900	24800	23100	21500
	400000	636000	82200	72000	64000	57700	52300	48000	44200	41200	38400	36000	32000	28800	26100	24000	22100	20600	19200
	350000	556500	71800	62800	55800	50200	45600	41800	38700	35800	33500	31400	27900	25100	22800	20900	19300	17900	16700
	300000	477000	61300	53600	47700	42800	39000	35700	33000	30600	28600	26800	23800	21400	19500	17850	16500	15300	14300
	250000	397500	51200	44800	39800	35800	32600	29900	27600	25600	23900	22400	19900	17900	16300	14900	13800	12800	11900
0000	211600	336420	43200	37900	33700	30300	27500	25200	23300	21600	20200	18950	16800	15100	13700	12600	11600	10800	[illegible]
000	167772	266800	34400	30100	26800	24100	21900	20100	18500	17200	16000	15050	13400	12000	10900	10000	9250	8600	8000
00	133079	211950	27100	23700	21100	19000	17300	15800	14600	13500	12600	11850	10500	9500	8650	7900	7300	6750	6300
0	105560	167800	21700	18900	16800	15100	13800	12600	11700	10800	10100	9450	8400	7550	6900	6300	5850	5400	5050
1	83694	133200	17100	14900	13300	11900	10800	9970	9200	8550	7970	7450	6650	5900	5400	4980	4600	4270	3980
2	66358	105530	13500	11800	10500	9470	8600	7880	7280	6770	6320	5900	5250	4730	4300	3940	3640	3380	3160
3	52624	83640	10700	9400	8350	7520	6830	6250	5780	5360	5000	4700	4170	3760	3410	3120	2890	2680	2500
4	41738	66370	8600	7500	6680	6000	5470	5000	4620	4300	4000	3750	3340	3000	2730	2500	2310	2150	2000
5	33088	52630	6780	5930	5270	4750	4320	3960	3660	3400	3170	2960	2630	2370	2160	1980	1830	1700	1580

50 000 VOLTS DELIVERED

B & S NO.	COPPER	ALUMINUM	20 MILES	24 MILES	28 MILES	32 MILES	36 MILES	40 MILES	44 MILES	48 MILES	52 MILES	56 MILES	60 MILES	64 MILES	72 MILES	80 MILES	88 MILES	96 MILES	104 MILES
	650000	1033000	120000	100000	86000	75000	66800	60000	54800	50200	46200	43000	40000	37500	33400	30000	27400	25100	23100
	600000	954000	111000	92500	79200	69200	61500	55500	50300	46200	42500	39600	37000	34600	30700	27700	25100	23100	21200
	550000	874500	103000	85500	73500	64200	57000	51300	46600	42800	39500	36700	34300	32100	28500	25600	23300	21400	19700
	500000	795000	92800	77200	66200	58000	51500	46400	42200	38700	35600	33100	30900	29000	25700	23200	21100	19300	17800
	450000	715500	83800	69500	59800	52200	46500	41800	38000	35000	32200	29900	27900	26100	23200	20900	19000	17500	16100
	400000	636000	74200	61800	53000	46300	41200	37100	33700	30900	28500	26500	24700	23200	20600	18500	16900	15400	14200
	350000	556500	64600	53800	46100	40400	35900	32300	29300	26900	24800	23100	21500	20200	17900	16100	14700	13400	12400
	300000	477000	55300	46100	39500	34600	30700	27600	25100	23000	21300	19700	18400	17300	15400	13800	12600	11500	10600
	250000	397500	46300	38600	33100	28900	25700	23100	21000	19300	17800	16500	15400	14500	12900	11600	10500	9640	8900
0000	211600	336420	39100	32500	27900	24400	21700	19500	17800	16200	15000	13900	13000	12200	10800	9760	8880	8140	7510
000	167772	266800	31100	25900	22200	19400	17300	15500	14100	13000	11900	11100	10400	9720	8640	7770	7070	6480	5980
00	133079	211950	24500	20400	17500	15300	13600	12200	11100	10200	9430	8750	8170	7660	6810	6130	5570	5100	4710
0	105560	167800	19500	16300	13900	12200	10800	9760	8880	8140	7510	6970	6510	6100	5420	4880	4440	4070	3760
1	83694	133220	15400	12900	11020	9640	8570	7710	7010	6430	5930	5510	5140	4822	4290	3860	3510	3210	2970
2	66358	105530	12200	10200	875	7660	6810	6130	5570	5100	4710	4370	4080	3833	3400	3060	2780	2550	2350
3	52624	83640	9690	8070	6920	6060	5380	4840	4400	4040	3730	3460	3230	3030	2690	2420	2200	2020	1860
4	41738	66370	7740	6450	5530	4840	4300	3870	3520	3220	2980	2760	2580	2420	2150	1930	1760	1610	1490
5	33088	52630	6140	5120	4390	3840	3410	3070	2790	2560	2360	2190	2050	1920	1710	1530	1400	1280	1180

60 000 VOLTS DELIVERED

B & S NO.	COPPER	ALUMINUM	20 MILES	24 MILES	28 MILES	32 MILES	36 MILES	40 MILES	44 MILES	48 MILES	52 MILES	56 MILES	60 MILES	64 MILES	72 MILES	80 MILES	88 MILES	96 MILES	104 MILES
	650000	1033000	173000	144000	124000	108000	96000	86600	78800	72200	66500	[illegible]	[illegible]	54000	48000	43300	39400	36100	33200
	600000	954000	159000	133000	114000	99500	88500	74600	72500	66300	[illegible]	57000	53200	49700	44200	39800	36200	33200	30700
	550000	874500	148000	123000	106000	92500	82200	74000	67300	61800	57000	52800	49400	46200	41100	37000	33600	30900	28500
	500000	795000	133000	111000	95000	83500	74000	66600	[illegible]	[illegible]	[illegible]	[illegible]	44400	41700	37000	33300	30200	27700	25600
	450000	[illegible]	120000	100000	85700	75200	[illegible]	60000	[illegible]	[illegible]	46300	[illegible]	40000	37600	33300	30000	27300	25100	[illegible]
	[illegible]	636000	107000	89000	76300	66700	[illegible]	53400	[illegible]	[illegible]	[illegible]	[illegible]	35600	33400	29700	[illegible]	24200	22200	20500
	[illegible]	[illegible]	93000	77500	66400	58100	51700	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	31000	29100	25800	23200	21100	19400	[illegible]
	[illegible]	[illegible]	79600	66300	56900	49800	44200	39800	36200	33100	[illegible]	[illegible]	[illegible]	24900	22100	19900	[illegible]	16600	15300
	[illegible]	397500	66700	55500	47600	41700	37000	[illegible]	[illegible]	[illegible]	[illegible]	23800	22200	20800	18500	16700	15100	13900	12800
0000	[illegible]	336420	56200	46900	40200	35100	31200	28100	[illegible]	[illegible]	[illegible]	20100	18700	17600	15600	14100	12800	11700	10800
000	[illegible]	266800	44800	37300	32000	28000	24800	22400	[illegible]	[illegible]	17200	[illegible]	14900	14000	12400	11200	10200	9330	8610
00	133079	[illegible]	35300	29400	25200	22000	19600	[illegible]	16000	14700	[illegible]	12600	[illegible]	11000	9800	8820	8020	7350	6790
0	105560	[illegible]	28100	23400	20100	17600	15600	[illegible]	[illegible]	[illegible]	10800	[illegible]	9370	8790	7810	7030	6390	5860	5410
1	83694	[illegible]	22200	18500	15800	13900	12300	[illegible]	[illegible]	9260	[illegible]	[illegible]	[illegible]	6940	6170	5550	5050	4630	4270
2	66358	[illegible]	[illegible]	14700	[illegible]	11000	[illegible]	8820	8020	7350	[illegible]	[illegible]	5880	5510	4900	4410	4010	3670	3390
3	52624	[illegible]	[illegible]	11600	[illegible]	8720	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4980	4650	4360	3880	3490	3170	2910	2680
4	41738	[illegible]	[illegible]	9290	[illegible]	6970	6190	[illegible]	[illegible]	[illegible]	4290	[illegible]	3710	3480	3100	2790	2530	2320	2140
5																			

The loss due to corona will not be excessive with any of the above conductors used at sea level for the voltages stated. For elevations above sea level check the values with Table XXII, especially for the smaller conductors. On long circuits of high voltage, the effect of charging current (also corona and leakage losses) will be to increase or decrease the I^2R loss, depending on the amount of load and its power-factor. See Fig. 13

TABLE XIX—QUICK ESTIMATING TABLE

KILOVOLT-AMPERES, 3 PHASE, WHICH MAY BE DELIVERED AT THE FOLLOWING VOLTAGES OVER THE VARIOUS CONDUCTORS FOR THE DISTANCES STATED. BASED UPON THE FOLLOWING I^2R LOSS (EFFECT OF CHARGING CURRENT NEGLECTED)

	AT 25° C	AT 65° C
FOR LOAD POWER-FACTOR OF 100%	8.66% LOSS	10.0% LOSS
FOR LOAD POWER-FACTOR OF 80%	10.8% LOSS	12.5 LOSS

66 000 VOLTS DELIVERED

B. & S. NO.	COPPER AREA IN CIRCULAR MILS	ALUMINUM AREA IN CIRCULAR MILS	20 MILES	24 MILES	28 MILES	32 MILES	36 MILES	40 MILES	44 MILES	48 MILES	52 MILES	56 MILES	60 MILES	64 MILES	72 MILES	80 MILES	88 MILES	96 MILES	104 MILES
	650 000	1 033 000	210000	174000	150000	131000	116000	105000	95300	87500	80800	75000	69800	65500	58000	52500	47600	43700	40400
	600 000	954 000	193000	161000	138000	120000	107000	96200	87500	80200	74200	68800	64300	60000	53500	48100	43700	40100	37100
	550 000	874 500	178000	148000	127000	111000	99000	89200	81000	74200	68700	63800	59500	55500	49500	44600	40600	37100	34300
	500 000	795 000	161000	134000	115000	101000	89500	80500	73300	67000	62000	57600	53700	50500	44700	40200	36600	33500	31000
	450 000	715 500	145000	121000	104000	91000	80700	72700	66000	60500	56000	51800	48500	45500	40300	36300	33000	30200	28000
	400 000	636 000	130000	108000	92700	81000	72000	65000	59000	54000	50000	46300	43300	40500	36000	32500	29500	27000	25000
	350 000	556 500	113000	94000	80500	70500	62500	56500	51500	47200	43500	40500	37700	35200	31200	28200	25700	23600	21700
	300 000	477 000	96000	80000	68700	60000	53500	48000	43700	40000	37000	34300	32000	30000	26700	24000	21800	20000	18500
	250 000	397 500	80500	67200	57600	50500	44700	40300	36700	33600	31000	28800	26900	25200	22300	20100	18300	16800	15500
0000	211 600	336 420	68000	56700	48700	42500	37700	34000	31000	28300	26100	24300	22700	21200	18800	17000	15500	14100	13000
000	167 772	266 800	54000	45000	38600	33900	30100	27100	24600	22500	20800	19300	18100	16900	15000	13500	12300	11200	10400
00	133 079	211 950	42500	35500	30400	26600	23700	21300	19300	17700	16300	15200	14200	13300	11800	10600	9650	8850	8150
0	105 560	167 800	34000	28400	24300	21300	18900	17000	15500	14200	13100	12200	11300	10600	9450	8500	7750	7100	6550
1	83 694	133 220	27000	22500	19300	16800	15000	13500	12200	11200	10400	9600	8900	8400	7500	6750	6100	5600	5200
2	66 358	105 530	21300	17800	15200	13300	11800	10600	9700	8900	8200	7600	7100	6650	5900	5300	4850	4450	4100
3	52 624	83 640	16800	14000	12000	10500	9300	8400	7600	7000	6400	6000	5600	5250	4670	4200	3820	3500	3240
4	41 738	66 370	13500	11200	9600	8400	7500	6700	6100	5600	5200	4800	4500	4210	3750	3375	3070	2810	2600

70 000 VOLTS DELIVERED

B. & S. NO.	COPPER	ALUMINUM	36 MILES	40 MILES	44 MILES	48 MILES	52 MILES	56 MILES	60 MILES	64 MILES	72 MILES	80 MILES	88 MILES	96 MILES	104 MILES	112 MILES	120 MILES	128 MILES	144 MILES
	650 000	1 033 000	130000	118000	107000	98000	90600	84000	78600	73500	65500	59000	53500	49000	45300	42000	39300	36700	32700
	600 000	954 000	120000	108000	98500	90500	83500	77500	72300	67700	60300	54000	49200	45200	41700	37700	36100	33800	30100
	550 000	874 500	112000	100000	91200	83500	77500	71700	67000	62600	55800	50000	45600	41700	37700	35800	33200	31300	27900
	500 000	795 000	101000	90500	82500	75500	69800	64800	60500	56700	50500	45200	41200	37700	34900	32400	30200	28300	25200
	450 000	715 500	90800	81600	74200	68000	62800	58500	54500	51000	45500	41800	37100	34000	31400	29200	27200	25500	22700
	400 000	636 000	80800	72700	66100	60600	55900	51900	48400	45400	40400	36300	33000	30300	28000	25900	24200	22700	20200
	350 000	556 500	70300	63300	57500	52700	48700	45200	42200	39500	35100	31600	28800	26400	24300	22600	21100	19700	17600
	300 000	477 000	60200	54200	49200	45100	41700	38700	36100	33900	30100	27100	24600	22600	20800	19300	18000	16900	15000
	250 000	397 500	50400	45300	41200	37800	34900	32400	30200	28300	25200	22700	20600	18900	17400	16200	15100	14200	12600
0000	211 600	336 420	42500	38300	34800	31900	29400	27300	25500	23900	21200	19100	17400	15900	14700	13600	12600	11900	10600
000	167 772	266 800	33800	30400	27700	25400	23400	21700	20300	19000	16900	15200	13800	12700	11700	10900	10100	9520	8460
00	133 079	211 950	26700	24000	21800	20000	18400	17100	16000	15000	13300	12000	10900	10000	9240	8580	8000	7500	6670
0	105 560	167 800	21200	19100	17400	15900	14700	13600	12700	12000	10600	9570	8700	7970	7360	6830	6380	6000	5310
1	83 694	133 220	16800	15100	13700	12600	11600	10800	10100	9450	8400	7560	6870	6300	5820	5400	5040	4720	4200
2	66 358	105 530	13300	12000	10900	10000	9240	8580	8000	7500	6670	6000	5460	5000	4620	4290	4000	3750	3330
		83 640	10500	9500	8630	7920	7300	6780	6330	5900	5270	4750	4320	3960	3670	3390	3160	2970	2640

80 000 VOLTS DELIVERED

B. & S. NO.	COPPER	ALUMINUM	36 MILES	40 MILES	44 MILES	48 MILES	52 MILES	56 MILES	60 MILES	64 MILES	72 MILES	80 MILES	88 MILES	96 MILES	104 MILES	112 MILES	120 MILES	128 MILES	144 MILES
	650 000	1 033 000	171000	154000	140000	128000	118000	110000	102000	96000	85500	77000	70000	64000	59000	55000	51000	48000	42700
	600 000	954 000	157000	142000	128000	118000	109000	101000	94500	88500	78500	[illegible]	64000	59000	54500	50500	47700	44200	39200
	550 000	874 500	146000	131000	119000	110000	101000	93600	87600	82000	72800	65500	59500	55000	50500	46800	43800	41000	36400
	500 000	795 000	132000	119000	108000	99000	91500	85000	79000	74200	66000	57500	54000	47500	45700	42500	39500	37100	33000
	450 000	715 500	118000	107000	97000	88800	82000	76200	71000	66700	59200	53500	48500	44400	41000	38100	35500	33300	29600
	400 000	636 000	105000	94900	86300	79100	73000	67800	63300	57300	[illegible]	47400	43100	39500	36500	33900	31600	29600	26300
	350 000	556 500	91800	82600	75100	68900	63600	54000	[illegible]	[illegible]	45400	41300	37500	34400	31800	29500	27500	20800	22900
	300 000	477 000	78600	70800	64300	59000	54400	[illegible]	47200	44200	39300	35400	32100	29300	27200	25300	23600	22100	19600
	250 000	397 500	65800	57200	53800	49400	45600	42300	39500	[illegible]	32900	29600	26900	24700	22800	21100	19700	18500	16400
0000	211 600	336 420	55500	50000	46400	41700	38400	35700	33300	31200	27500	25000	22700	20800	19200	17800	16700	15600	13900
000	167 772	266 800	44200	39800	36200	33100	[illegible]	28400	26500	24800	22100	19400	18100	16600	15300	14200	13200	12400	11000
00	133 079	211 950	34800	31300	28500	26100	[illegible]	22400	20900	[illegible]	[illegible]	15600	14200	13100	12100	11200	10400	9800	8700
0	105 560	167 800	27800	25000	22700	20800	19200	[illegible]	16700	15600	13400	12500	11300	10400	9610	8930	8330	7810	6940
1	83 694	133 220	21900	19700	17900	16400	15200	[illegible]	13100	12300	10400	9880	8980	8230	7600	7050	6580	6170	5490
		105 530	17400	15700	14200	13100	[illegible]	11200	10400	9800	8710	7840	7130	6530	6030	5600	5230	4900	4360

88 000 VOLTS DELIVERED

B. & S. NO.	COPPER	ALUMINUM	36 MILES	40 MILES	44 MILES	48 MILES	52 MILES	56 MILES	60 MILES	64 MILES	72 MILES	80 MILES	88 MILES	96 MILES	104 MILES	112 MILES	120 MILES	128 MILES	144 MILES
	650 000	1 033 000	207000	186000	169000	155000	143000	133000	124000	116000	103000	93000	84500	77500	71500	66500	62000	58000	51500
	600 000	954 000	191000	171000	156000	143000	132000	122000	114000	107000	95500	85500	78000	71500	66000	61000	57000	53500	47700
	550 000	874 500	177000	159000	144000	132000	122000	113000	106000	99500	88200	79500	72000	66000	61000	56500	53000	49700	44100
	500 000	795 000	159000	143000	131000	120000	111000	102000	96000	90000	80000	71500	65500	60000	55500	51000	48000	45000	40000
	450 000	715 500	143000	129000	117000	107000	99000	92000	86000	80500	71500	64500	58500	53500	49500	46000	43000	40300	35700
	400 000	636 000	128000	115000	105000	96000	88700	82500	76800	72000	64000	57500	52500	48000	44300	41200	38400	36000	32000
	350 000	556 500	111000	100000	91200	83500	77200	71600	67000	62700	55800	50000	45600	41750	38600	35800	33500	31300	27900
	300 000	477 000	95000	85500	78000	71500	66000	61200	57200	53600	47700	42700	39000	35700	33000	30600	28600	26800	23800
	250 000	397 500	79500	71500	65000	59800	55000	51000	47800	44800	39800	35700	32500	29900	27500	25500	23900	22400	19900
0000	211 600	336 420	67200	60500	55000	50500	46200	43200	40300	37800	33600	30200	27500	25200	23200	21600	20100	18900	16800
000	167 772	266 800	53500	48200	43800	40200	37000	34400	32200	30200	26800	24100	21900	20100	18500	17200	16100	15100	13400
00	133 079	211 950	42300	38000	34600	31700	29300	27200	25400	23800	21200	19100	17300	15800	14600	13600	12700	11900	10600
0	105 560	167 800	33700	30300	27600	25300	23300	21100	20200	19000	16800	15100	13800	12600	11600	10800	10100	9500	8400
1	83 694	133 220	26500	23900	21700	19900	18300	17000	15900	14900	13200	11900	10850	9900	9100	8500	7900	7400	6600
		105 530	21100	19000	17200	15800	14600	13500	12600	11900	10500	9500	8600	7900	7300	6700	6300	5900	5200

The loss due to corona will not be excessive with any of the above conductors used at sea level for the voltages stated. For elevations above sea level, check the values with Table XXII, especially for the smaller conductors. On long circuits of high voltage, the effect of charging current (also corona and leakage losses) will be to increase or decrease the I R loss, depending on the amount of load and its power-factor. See Fig. 13

TABLE XX—QUICK ESTIMATING TABLE

CONDUCTORS — B & S No.; COPPER AREA IN CIRCULAR MILS; ALUMINUM AREA IN CIRCULAR MILS

KILOVOLT-AMPERES, 3 PHASE, WHICH MAY BE DELIVERED AT THE FOLLOWING VOLTAGES OVER THE VARIOUS CONDUCTORS FOR THE DISTANCES STATED. BASED UPON THE FOLLOWING I^2R LOSS (EFFECT OF CHARGING CURRENT NEGLECTED)

	AT 25° C	AT 65° C
FOR LOAD POWER-FACTOR OF 100%	8.66% LOSS	10.0% LOSS
FOR LOAD POWER-FACTOR OF 80%	10.8% LOSS	12.5 LOSS

100 000 VOLTS DELIVERED

B & S No.	Copper	Aluminum	52 Miles	56 Miles	60 Miles	64 Miles	72 Miles	80 Miles	88 Miles	96 Miles	104 Miles	112 Miles	120 Miles	128 Miles	144 Miles	160 Miles	176 Miles	192 Miles	208 Miles
	650 000	1 033 000	185000	172000	160000	150000	133000	120000	109000	100000	92500	86000	80000	75000	66500	60000	54500	50000	46200
	600 000	954 000	170000	158000	148000	138000	123000	110000	101000	92500	85500	79000	74000	69000	61500	55000	50500	46200	42700
	550 000	874 500	158000	147000	137000	128000	114000	103000	93500	85500	79000	73500	68500	64000	57000	51500	46700	42700	39500
	500 000	795 000	143000	132000	124000	116000	103000	93000	84500	77500	71500	66000	62000	58000	51500	46500	42200	38700	35700
	450 000	715 500	128000	119000	111000	104000	93000	83500	76000	69500	64200	59500	55500	52000	46500	41700	38000	34700	32100
	400 000	636 000	114000	106000	98900	92700	82400	74200	67400	61800	57000	53000	49400	46300	41200	37100	33700	30900	28500
	350 000	556 500	99400	92300	86100	80700	71800	64600	58700	53800	49700	46100	43000	40300	35900	32300	29300	26900	24800
	300 000	477 000	85100	79000	73700	69100	61400	55300	50300	46100	42500	39500	36800	34500	30700	27600	25100	23000	21200
	250 000	397 500	72200	66100	61700	57800	51400	46300	42100	38600	35600	33000	30800	28900	25700	23100	21000	19300	17800
0000	211 600	336 420	61100	55800	52100	48800	43400	39000	35500	32500	30000	27900	26000	24400	21700	19500	17700	16200	15000
000	167 772	266 800	47800	44400	41400	38800	34500	31100	28200	25900	23900	22200	20700	19400	17200	15500	14100	12900	11900
00	133 079	211 950	37700	35000	32700	30600	27200	24500	22300	20400	18800	17500	16300	15300	13600	12200	11100	10200	9400
0	105 560	167 800	30000	27900	26000	24400	21700	19500	17700	16300	15000	13900	13000	12200	10800	9800	8900	8100	7500
		133 220	23700	22000	20600	19300	17100	15400	14000	12900	11900	11000	10300	9600	8600	7700	7000	6400	5900
		105 530	18800	17500	16300	15300	13600	12200	11100	10200	9400	8700	8200	7600	6800	6100	5600	5100	4700

110 000 VOLTS DELIVERED

B & S No.	Copper	Aluminum	52 Miles	56 Miles	60 Miles	64 Miles	72 Miles	80 Miles	88 Miles	96 Miles	104 Miles	112 Miles	120 Miles	128 Miles	144 Miles	160 Miles	176 Miles	192 Miles	208 Miles
	650 000	1 033 000	224000	208000	194000	182000	162000	146000	133000	121000	112000	104000	97000	91000	81000	73000	66500	60500	56000
	600 000	954 000	206000	191000	178000	167000	148000	134000	122000	111000	103000	95500	89000	83500	74000	67000	61000	55500	51500
	550 000	874 500	191000	177000	165000	155000	138000	124000	113000	103000	95500	88500	82500	77500	69000	62000	56500	51500	47700
	500 000	795 000	173000	160000	150000	140000	125000	112000	102000	93500	86000	80000	75000	70000	62500	56000	51000	46700	43000
	450 000	715 500	155000	144000	134000	126000	112000	101000	91600	84000	77600	72000	67000	63000	56000	50500	45800	42000	38800
	400 000	636 000	138000	128000	119000	112000	99700	89700	81600	74800	69000	64100	59800	56100	49800	44900	40800	37400	34500
	350 000	556 500	120000	111000	104000	97700	86800	78100	71000	65100	60100	55800	52100	48800	43400	39100	35500	32500	30000
	300 000	477 000	103000	95600	89200	83600	74300	66900	60800	55700	51500	47800	44600	41800	37210	33400	30400	27900	25700
	250 000	397 500	86100	80000	74700	70000	62200	56000	50600	46600	43100	40000	37300	35000	31100	28000	25300	23300	21500
0000	211 600	336 420	72700	67500	63000	59[illegible]00	52500	47200	42900	39400	36300	33700	31500	29500	26200	23600	21500	19700	18200
000	167772	266 800	57800	53700	50100	47000	41800	37600	34200	31300	28900	26800	25100	23500	20900	18800	17100	15600	14400
00	133079	211 950	45600	42300	39500	37000	32900	29600	26900	24700	22800	21100	19800	18500	16400	14800	13500	12300	11400
		167 800	36300	33700	31500	29500	26200	23600	21400	19700	18100	16900	15700	14700	13129	11800	10700	9800	9100
		133 220	28700	26600	24900	23300	20700	18600	16900	15500	14300	13300	12400	11670	10300	9300	8500	7800	7200

120 000 VOLTS DELIVERED

B & S No.	Copper	Aluminum	64 Miles	72 Miles	80 Miles	88 Miles	96 Miles	104 Miles	112 Miles	120 Miles	128 Miles	144 Miles	160 Miles	176 Miles	192 Miles	208 Miles	224 Miles	240 Miles	256 Miles
	650 000	1 033 000	216000	192000	173000	157000	144000	133000	123000	115000	108000	96000	86500	78500	72000	66500	61500	57500	54000
	600 000	954 000	199000	177000	160000	145000	133000	123000	114000	106000	100000	88500	80000	72500	66500	61500	57000	53000	50000
	550 000	874 500	184000	164000	148000	134000	123000	113000	105000	98500	92500	82000	74000	67000	61500	56500	52500	49200	46200
	500 000	795 000	167000	148000	133000	121000	111000	102000	95000	89000	83500	74000	66500	60500	55500	51000	47500	44500	41700
	450 000	715 500	150000	133000	120000	109000	100000	92500	86000	80000	75000	66500	60000	54500	50000	46200	43000	40000	37500
	400 000	636 000	133000	119000	107000	97100	89000	82100	76300	71200	66700	59300	53400	48500	44500	41100	38100	35600	33300
	350 000	556 500	[illegible]	103000	93000	84500	77500	71500	66400	62000	58100	51600	46500	42200	38700	35800	33200	31000	29100
	300 000	477 000	99600	88500	79600	72400	66400	61200	56900	53100	49800	44200	39800	36200	33100	30600	28400	26500	24800
	250 000	397 500	83300	74000	66700	60600	55500	51200	47600	44400	41600	37000	33300	30300	27700	25600	23800	22200	20800
0000	211 600	336 420	70300	62500	56200	51[illegible]00	46800	43200	40100	37500	35100	31200	28100	25500	23400	21600	20100	18700	17500
000	167772	266 800	[illegible]	[illegible]	44800	[illegible]	37300	34400	32000	29800	28000	24800	22300	20300	18600	17200	16000	14900	14000
		211 950	[illegible]	39200	35300	32[illegible]00	29400	27100	25200	23500	22000	19600	17600	16000	14700	13500	12600	11700	11000
		167 800	[illegible]	31200	28100	25600	23400	21600	20[illegible]00	18700	17500	15600	14000	12700	11700	10800	10000	9300	8800

132 000 VOLTS DELIVERED

B & S No.	Copper	Aluminum	64 Miles	72 Miles	80 Miles	88 Miles	96 Miles	104 Miles	112 Miles	120 Miles	128 Miles	144 Miles	160 Miles	176 Miles	192 Miles	208 Miles	224 Miles	240 Miles	256 Miles
	650 000	1 033 000	[illegible]	233000	210000	191000	175000	161000	150000	140000	131000	116000	105000	95500	87500	80500	75000	70000	65500
	600 000	954 000	[illegible]	[illegible]	193000	176000	161000	148000	138000	129000	121000	107000	96500	88000	80500	74000	69000	64500	60500
	550 000	874 500	223000	[illegible]	[illegible]	162000	149000	137000	128000	109000	[illegible]	99000	89000	81000	74500	68500	64000	54500	56000
	500 000	795 000	[illegible]	[illegible]	161000	147000	134000	124000	115000	107000	101000	89500	80500	73500	67000	62000	57500	53500	53050
	450 000	715 500	[illegible]	[illegible]	145000	132000	121000	112000	104000	96800	90800	80500	72500	66000	60500	56000	52000	48400	45400
	400 000	636 000	[illegible]	144000	129000	118000	108000	100000	92700	86500	81000	72000	64500	59000	54000	50000	46300	43200	40500
	350 000	556 500	140000	125000	112000	102000	93500	86500	80500	75000	70300	62500	56000	51000	46750	43200	40200	37500	35100
	300 000	477 000	120000	107000	96000	87500	80000	74000	68700	64000	60000	53500	48000	43700	40000	37000	34300	32000	30000
	250 000	397 500	100000	89300	80500	73000	67000	62000	57500	53700	50200	44600	40200	36500	33500	31000	28700	26800	25100
0000	211 600	336 420	85000	75500	68000	61800	56700	52300	48500	45300	42500	37700	34000	30900	28300	26100	24200	22600	21200
		266 800	67700	60200	54200	49300	45200	41700	38700	36100	33900	30100	27100	24600	22600	20800	19300	18000	16900
		211 950	53000	47500	42700	38800	35600	32900	30500	28500	26800	23700	21300	19400	17800	16400	15200	14200	13400

140 000 VOLTS DELIVERED

B & S No.	Copper	Aluminum	64 Miles	72 Miles	80 Miles	88 Miles	96 Miles	104 Miles	112 Miles	120 Miles	128 Miles	144 Miles	160 Miles	176 Miles	192 Miles	208 Miles	224 Miles	240 Miles	256 Miles
	650 000	1 033 000	293000	262000	236000	215000	196000	181000	168000	157000	147000	131000	118000	107000	98000	90500	84000	78500	73500
	600 000	954 000	272000	242000	[illegible]	197000	[illegible]	167000	156000	145000	136000	121000	108000	98500	90500	83500	78000	72500	68000
	550 000	874 500	251000	223000	[illegible]	182000	167000	155000	143000	134000	126000	111000	100000	91000	83500	77500	71500	67000	63000
	500 000	795 000	226000	201000	[illegible]	165000	151000	140000	130000	121000	113000	101000	90700	82500	75600	69800	64800	60500	56700
	450 000	715 500	203000	[illegible]	163000	148000	135000	125000	116000	108000	102000	90400	81400	74000	67800	62600	58100	54200	50800
	400 000	636 000	[illegible]	[illegible]	145000	132000	121000	112000	104000	96900	90800	80800	72700	66100	60600	55900	51900	48400	45400
	350 000	556 500	158000	140000	127000	115000	105000	97400	90400	84400	79100	70300	63300	57500	52700	48700	45200	42200	39600
	300 000	477 000	135000	120000	108000	98500	90300	83400	77400	72200	67700	60200	54200	49300	45100	41700	38700	36100	33800
	250 000	397 500	[illegible]	101000	90700	82500	75600	69800	64800	60500	56700	50400	45400	41300	37800	34900	32400	30200	28300
0000	211 600	336 420	[illegible]	85000	76500	69600	63800	58900	54700	51000	47800	42500	38300	34800	31900	29400	27300	25500	23900
		266 800	[illegible]	67700	61000	55400	50800	46900	43500	40600	38100	33800	30500	27700	25400	23400	21800	20300	19000
		211 950	60000	53400	48000	43700	40000	36900	34300	32000	30000	26700	24000	21800	20000	18500	17100	16000	15000

The loss due to corona [illegible] not be excessive with any of the above conductors used at sea level for the voltages stated. For elevations above sea level check the values with Table XXII, especially for the smaller conductors. On long circuits of high voltage, the effect of charging current [illegible] voltage losses will be to increase or decrease the I^2R loss, depending on the amount of load and its power factor. See Fig. 13

HEATING LIMITATIONS

The k.v.a. values given in these tables do not take into account the heating and consequently carrying capacity of the conductors. This may be ignored in the case of the longer overhead high-voltage transmission circuits. For very short circuits (especially for the lower voltages and particularly for insulated or concealed conductors) the carying capacity (safe heating limits) of the conductors must be carefully considered. approximately the point at which the carrying capacity of that particular conductor is reached if insulated and installed in a fully loaded four duct line. If the conductor is to be installed in a duct line having more than four ducts its capacity will be still further reduced. The position of this line is based upon the use of lead covered, paper insulated, three conductor, copper cables for sizes up to 700 000 circ. mils and of lead covered, paper insulated, single conductor, copper cables for the larger sizes. In other words, the position of this heavy

TABLE XXI—QUICK ESTIMATING TABLE

CONDUCTORS

KILOVOLT-AMPERES, 3 PHASE, WHICH MAY BE DELIVERED AT THE FOLLOWING VOLTAGES OVER THE VARIOUS CONDUCTORS FOR THE DISTANCES STATED. BASED UPON THE FOLLOWING I^2R LOSS (EFFECT OF CHARGING CURRENT NEGLECTED)

	AT 25° C	AT 65° C
FOR LOAD POWER-FACTOR OF 100%	8.66% LOSS	10.0% LOSS
FOR LOAD POWER-FACTOR OF 80%	10.8% LOSS	12.5 LOSS

154,000 VOLTS DELIVERED

COPPER AREA IN CIRCULAR MILS	ALUMINUM AREA IN CIRCULAR MILS	96 MILES	104 MILES	112 MILES	120 MILES	128 MILES	144 MILES	160 MILES	176 MILES	192 MILES	208 MILES	224 MILES	240 MILES	256 MILES	288 MILES	320 MILES	352 MILES	384 MILES
650 000	1 033 000	237 500	219 500	203 500	190 000	[illegible]	[illegible]	[illegible]	[illegible]	118 500	[illegible]	102 000	95 000	89 000	79 200	71 200	64 700	59 300
600 000	954 000	219 000	202 000	187 500	175 000	161 000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	93 500	87 500	82 000	73 000	65 700	59 700	54 700
550 000	874 500	202 000	187 000	173 000	161 500	[illegible]	134 500	[illegible]	[illegible]	101 000	93 300	[illegible]	80 800	75 700	67 300	60 700	55 200	50 500
500 000	795 000	183 500	169 000	157 000	146 500	[illegible]	[illegible]	[illegible]	99 500	91 500	84 500	[illegible]	[illegible]	68 700	61 000	55 000	50 000	45 700
450 000	715 500	164 500	152 000	141 000	131 600	123 500	109 500	[illegible]	89 800	82 300	76 000	70 600	65 800	61 700	54 800	49 300	44 900	41 200
400 000	636 000	147 000	136 000	126 500	117 500	110 500	98 000	88 300	80 200	73 500	[illegible]	63 000	58 800	55 200	49 000	44 200	40 200	36 800
350 000	556 500	128 200	118 500	109 500	102 500	96 000	85 300	76 800	69 800	64 000	59 200	54 800	51 200	48 000	42 700	38 500	35 000	32 100
300 000	477 000	109 500	102 000	94 000	87 500	82 000	73 000	65 700	59 700	54 700	50 500	46 800	43 700	41 000	36 500	32 800	29 800	27 300
250 000	397 500	91 500	84 500	78 500	73 200	68 600	61 000	54 800	49 800	45 700	42 200	39 200	36 600	34 300	30 500	27 400	24 900	22 900
	336 420	77 200	71 200	66 200	61 600	57 700	51 500	46 200	42 000	38 500	35 600	33 000	30 800	28 900	25 700	23 200	21 000	19 200
	266 800	61 500	56 800	52 700	49 200	46 100	41 000	36 900	33 600	30 700	28 400	26 400	24 600	23 100	20 500	18 400	16 800	15 400

187,000 VOLTS DELIVERED

COPPER	ALUMINUM	96 MILES	104 MILES	112 MILES	120 MILES	128 MILES	144 MILES	160 MILES	176 MILES	192 MILES	208 MILES	224 MILES	240 MILES	256 MILES	288 MILES	320 MILES	352 MILES	384 MILES
650 000	1 033 000	350 000	323 000	300 000	280 000	263 000	234 000	210 000	191 000	[illegible]	[illegible]	[illegible]	140 000	[illegible]	116 500	105 000	95 200	87 500
600 000	954 000	323 000	297 000	277 000	258 000	242 000	215 000	193 500	[illegible]	[illegible]	[illegible]	139 000	129 000	[illegible]	107 500	97 000	88 000	80 700
550 000	874 500	299 000	275 000	256 000	239 000	224 000	[illegible]	[illegible]	162 500	[illegible]	137 500	[illegible]	[illegible]	112 000	99 500	89 500	81 500	74 600
500 000	795 000	270 000	250 000	232 000	216 000	203 000	[illegible]	162 000	147 500	135 000	125 000	[illegible]	[illegible]	101 000	90 000	81 000	73 700	67 600
450 000	715 500	243 000	225 000	209 000	194 500	182 000	162 000	[illegible]	132 500	121 500	[illegible]	104 300	[illegible]	91 000	81 000	73 000	66 200	60 700
400 000	636 000	217 000	200 000	185 500	173 500	162 500	144 500	130 000	118 500	108 500	100 000	93 000	86 700	81 300	72 200	65 000	59 000	54 200
	556 500	189 000	[illegible]	162 000	151 000	[illegible]	126 000	113 500	103 000	94 500	87 000	81 000	75 500	70 800	63 000	56 700	51 500	47 200
	477 000	161 000	149 000	138 000	129 000	121 000	107 500	96 500	88 000	80 500	74 300	69 000	64 500	60 500	53 700	48 300	44 000	40 300
	397 500	134 500	124 500	115 500	107 500	101 000	[illegible]	80 800	73 500	[illegible]	62 200	57 800	53 800	50 500	44 800	40 400	36 800	33 700
	336 420	114 000	105 000	97 500	91 000	85 200	[illegible]	68 200	62 000	57 000	52 600	48 300	45 500	42 700	38 000	34 200	31 000	28 500

220,000 VOLTS DELIVERED

COPPER	ALUMINUM	96 MILES	104 MILES	112 MILES	120 MILES	128 MILES	144 MILES	160 MILES	176 MILES	192 MILES	208 MILES	224 MILES	240 MILES	256 MILES	288 MILES	320 MILES	352 MILES	384 MILES
650 000	1 033 000	485 000	447 000	417 000	388 000	364 000	323 000	291 000	265 000	243 000	224 000	208 000	194 000	182 000	162 000	145 500	132 500	121 500
	954 000	447 000	413 000	383 000	358 000	336 000	298 000	268 000	244 000	224 000	207 000	192 000	179 000	168 000	149 000	134 500	122 000	112 000
	874 500	413 000	382 000	354 000	331 000	310 000	276 000	249 000	226 000	207 000	[illegible]	177 500	165 500	155 000	138 000	124 000	112 800	103 500
	795 000	374 000	345 000	321 000	299 000	281 000	249 000	224 000	204 000	187 000	173 000	160 000	149 500	140 500	124 500	112 500	102 000	93 500
	715 500	336 000	310 000	288 000	269 000	252 000	224 000	202 000	183 500	168 000	155 000	144 000	134 500	126 000	112 000	101 000	92 000	84 200
	636 000	300 000	277 000	257 000	240 000	225 000	200 000	180 000	163 500	150 000	138 500	128 500	120 000	112 500	100 000	90 000	82 000	75 000

The loss due to corona will not be excessive with any of the above conductors used at sea level for the voltages stated. For elevations above sea level, check the values with Table XXII, especially for the smaller conductors. On long circuits of high voltage, the effect of charging current (also corona and leakage losses) will be to increase or decrease the I^2R loss, depending on the amount of load and its power-factor. See Fig. 13

For circuits of short length the carrying capacity of conductors will frequently determine these sizes and not the economic transmission loss. The carrying capacity of bare copper conductors suspended in air and of insulated copper conductors in duct lines are given in tables XXIII and XXV, both of which are to appear in subsequent articles.

Running diagonally across each table from XII to XVII inclusive, is a heavy line. The point at which this heavy line intersects the horizontal line containing the k.v.a. values for a given size of conductor indicates line is based upon the k.v.a. values for carrying capacity given in Table XXV and is placed upon the tables as a warning that the heating limit capacity of the conductors must be considered. To illustrate, suppose 220 volts is to be delivered, over 1 000 000 circ. mil, insulated, single conductor, copper cables in a fully loaded four duct conduit. Table XII indicates that 189 k.v.a. can be transmitted over these conductors a distance of 2000 ft. without overheating the cable. If it is desired to transmit 378 k.v.a. a distance of 1000 feet, the fact that this value occurs to the left of the heavy line, indicates that

it is beyond the safe carrying capacity for this size conductor in a four duct line. Reference to Table XXV will show that 297 k.v.a. is the maximum capacity of this cable under the conditions stated. In this case, either a larger conductor, or two or more smaller conductors must be used to prevent overheating. This will result in a less loss than those upon which the table k.v.a. values are based, and in this case the heating of the cable will probably determine the size to use.

EFFECT OF CHARGING CURRENT IN ABOVE I^2R LOSS VALUES

As stated previously, the percent I^2R losses in the quick estimating tables are based upon the load current and therefore do not take into account the effect of the charging current which is of a distributed nature and superimposed upon the load current. The effect of the charging current is to increase or decrease the current in the circuit by an amount depending upon the relative values of the lagging and leading quadrature components of the current in the circuit.

For instance assume that the power-factor of the load is unity. In such case there is no quadrature component in the load current. If, however, the circuit is of considerable length, and particularly if the frequency is 60 cycles, there will be an appreciable amount of charging current (quadrature leading component) added vectorially to the load current. The sum of these two currents in quadrature with each other will result in an increase of current in the circuit with a consequent increase in the I^2R loss. Thus the effect of charging current in a circuit delivering a load of 100 percent power-factor will always be to increase the I^2R loss.

If, however, the power-factor of the load is lagging, there will be a lagging component in the load current. The charging or leading current will be practically in opposition to the lagging component of the load current and will therefore tend to cancel or neutralize the lagging component of the load current. The result will be a reduction of the current in the circuit and consequently in the I^2R loss. But if the circuit is very long, particularly if the frequency is 60 cycles and the load power-factor is near unity (lagging component in load current small) the comparatively large leading component (charging current) will not only neutralize the lagging component of the load current, but will produce a leading power-factor at points along the circuit. If the charging current is sufficiently high it will increase the current, causing an increase in the I^2R loss. Thus the effect of charging current in circuits delivering a lagging load is to decrease the I^2R loss up to a certain amount and then, if the charging current is sufficiently large, to increase I^2R loss.

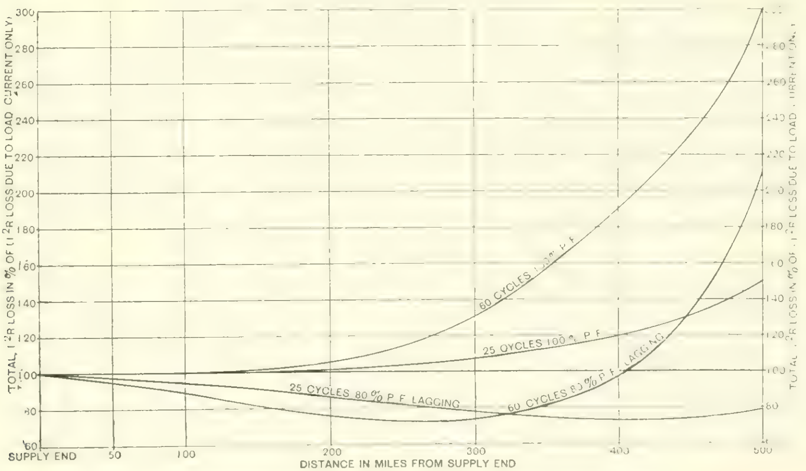


FIG. 13—EFFECT OF CHARGING CURRENT ON I^2R TRANSMISSION LOSS

The curves represent (for certain circuits) an approximation of the resultant I^2R loss, compared to what it would have been if there were no charging current present in the circuit. The effect of the charging current superimposed upon the receiver current is either to increase or to decrease the I^2R loss of the circuit depending principally upon the relative amount of the leading and lagging components of the current in the circuit.

The curves in Fig. 13 show this effect for 25 and 60 cycle circuits delivering loads of unity power-factor; also loads of 80 percent lagging power-factor for circuits up to 500 miles long. It will be seen that for circuits 300 miles long the effect of charging current will be to reduce the I^2R loss by approximately 25 percent if the load is 80 percent lagging. If the load power-factor is unity the I^2R loss will be increased approximately 10 percent for these particular problems if the frequency is 25, and 30 percent if the frequency is 60 cycles.

The curves in Fig. 13 show that for circuits 500 miles long, in which the entire charging current is furnished from one end of the circuit, the effect of this charging current is to increase the I^2R loss by 300 percent if the frequency is 60 cycle and the load power-factor 100 percent. In other words a large part of the current in the circuit for such a long 60 cycle circuit is charging current so that the effect of the load current on the I^2R loss is comparatively small. Of course such a long circuit, unless fed from two or more generating stations located at widely separated points along the transmission line, would not be commercially practical.

Transformers and Connections to Electric Furnaces

J. F. Peters

In the last few years, electric furnace applications have made tremendous progress both in numbers and in size. Since the voltage required is approximately the same for large and small electric furnaces, the advance in size of units has involved the handling of larger currents. Before the advent of large furnaces, the matter of getting the current into the furnace offered no difficulties whatever. Practically any kind of leads with the proper cross-section could be used, without requiring special precautions to obtain reasonable temperatures and reasonably low reactance drops in the leads between the supply transformer and the furnace. impedance, therefore it distributes in such manner as will decrease the magnetic reactions of the elements of current one on the other and thus decrease the reactance voltage. An unequal distribution of current increases the ohmic resistance drop. The final distribution of current is such that it strikes a compromise between decreasing the reactance and increasing the ohmic drops in voltage. Reactance increases with frequency and it is therefore very evident that the higher the frequency the greater will the current depart from uniform distribution in striking the compromise between reactance and resistance.

Figs. 1, 2 and 3 [illegible]

Fig. 1—Transformer out of case. [illegible] Fig. 3—Rear view.

But for large furnaces requiring 50 000 or even 10 000 amperes, especially at 60 cycles, it is necessary to exercise great care in designing the leads in order to make the outfit operative. For the larger currents it is probably as difficult, to build satisfactory leads between the transformers and the furnaces as it is to build satisfactory transformers for that service. This is especially true where considerable flexibility in the leads is required, to allow for tilting the furnace in discharging, and for the travel of the electrodes as they become consumed by the furnace.

Alternating-current flowing through large conductors does not distribute uniformly throughout their cross-section. The magnetic field set up by the current in different parts of the conductor reacts on the current. The current always seeks the path of least

The elements of current in any conductor or set of conductors tend to separate or get as far apart as possible, while the elements of current in different conductors carrying current in opposite directions attract each other. The current distribution in any conductor then depends upon frequency, size of conductor and nearness to return circuit.

In the conductor shown in Fig. 4, the edges of the bar carry approximately 1.75 times their normal density, while in the center of the bar the density is approximately one half normal. The heat generated in the center, then, is approximately one fourth normal while at the edges it is three times normal. The total heat generated is 115 percent normal. Although heat is being generated approximately twelve times as fast at the edges of the bar as in the center, the difference in

temperature between the edges and the center would be only slight on account of the high heat conductivity of copper and the resultant flow of heat from the edges of the bar towards the center. The conditions given in Fig. 5 are quite different so far as temperatures are concerned. There is no heat flow from one bar to the other, therefore an unequal division of current results in unequal temperatures.

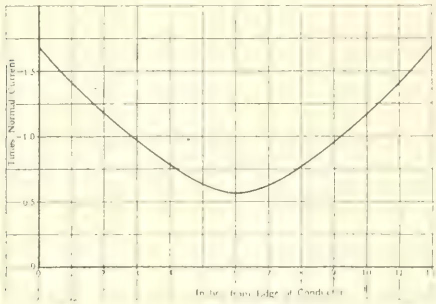


FIG. 4—CURRENT DISTRIBUTION AT 60 CYCLES IN ONE ONE-QUARTER BY TWELVE INCH BUS-BAR

At a considerable distance from its return circuit.

It is well to use as few bars in parallel per lead as possible. A single bar, 1/4 by 12 in., is preferable to two bars, 1/4 by 6 in. The bars should not exceed 5-16 in. thickness for 60 cycles or 3/8 in. for 25 cycles, and should be spaced a distance of not less than their thickness.

The flexible leads are most conveniently made up of a number of bare flexible copper cables bunched together. For currents up to 15 000 amperes at 60 cycles, or 20 000 amperes at 25 cycles, it is generally not necessary to transpose the cables of the flexible leads to get satisfactory operating conditions, but for large currents it will be found necessary to transpose them; that is, the cables that are nearest the center of the group and those that are at the edges of the group should exchange places at or near the center of the length. Flexible leads for large currents, if of any considerable length, have a material reactance voltage in them. For some types of furnaces, reactance in the leads is not objectionable. In fact some have reactors connected within the leads, while other types operate satisfactorily without the use of reactors. It is desirable to keep the lead reactance as low as possible in order to get high power factor operation.

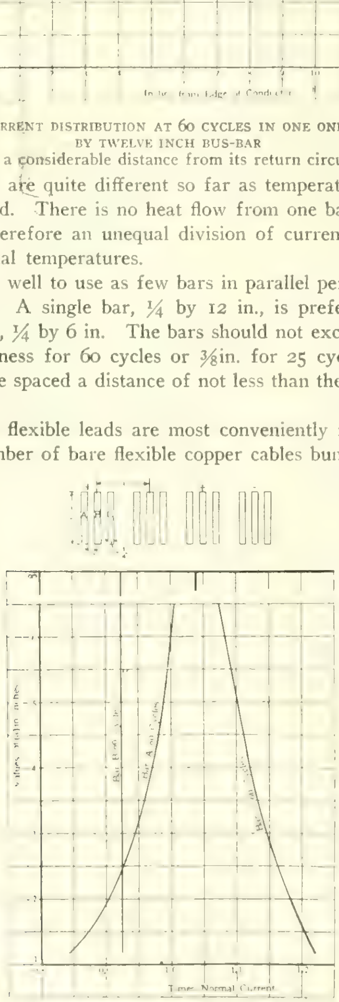


FIG. 5—DIVISION OF CURRENT IN THREE ONE-QUARTER BY TWELVE INCH COPPER BARS FORMING ONE LEAD

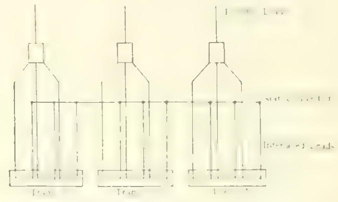


FIG. 6—INTERLACING OF LEADS

For three single phase transformers connected in star.

Due to large fluctuations in load, especially when melting down charges in steel furnaces, the transformers should be of a rugged construction, capable of withstanding considerable magnetic and electrical strains. A transformer built for furnace work is shown in Figs. 1, 2 and 3 which, from the nature of its construction, is well suited for this service. The windings in this transformer are made up of coils subdivided into groups of high-voltage and low-voltage coils. The windings are made up of a number of flat coils, each of which is wound of copper ribbon with only one turn per layer. This construction keeps the voltage stresses between adjacent turns low and exposes at least one side of each coil to a cooling duct. Vertical oil ducts are provided throughout the windings, which permit an adequate circulation of oil through the windings and insure a low and uniform temperature throughout. With currents of 10 000 amperes or more it is necessary to divide the low-voltage windings into a number of parallel circuits, in order to obtain good current distribution within the windings and to prevent abnormally high reactance within the transformer. It is rather fortunate that it works out conveniently to arrange the

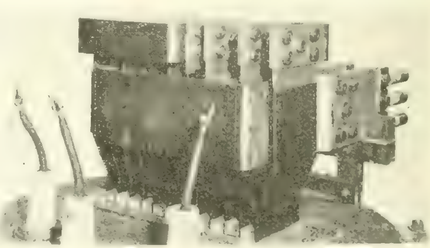


FIG. 7—DELTA CONNECTION OF TRANSFORMER LEADS OUTSIDE OF CASE

low-voltage winding in several parallels, as it is necessary to split up the leads in order to get reasonably good current distribution in them. In general a current that can conveniently be handled in one of the transformer parallel circuits can be handled in the leads without further interlacing. The transformer leads are generally made of copper bars and are interlaced so that no one lead carries more than 7000 to 7500 amperes.

To reduce the reactance and unequal distribution of current to a minimum, it is good practice to use interlaced bus construction similar to the transformer leads, in the connection between the transformers and furnace up to the point where the flexible leads start. The interphase connections, such as delta or star jumpers, should be made as near the furnace as possible. Generally the most suitable place to make these connections is at the point where the interlaced leads end and the flexible leads begin. An arrangement of this kind is shown in Fig. 6 for three single-phase transformers connected in star.

It is sometimes possible to locate the transformers close to the furnace so that the leads between transformer and furnace consist only of flexibles. In such cases it may be convenient to make the interphase connections on the top of the transformer. A transformer with this arrangement is shown in Fig. 7. The flexibles for this installation consist of eight cables per lead. The transformer leads are brought through the cover interlaced and the delta formed above the cover of the transformer.

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

SEPTEMBER 1919

Maintenance of Fuse Boxes for Railway Service

The fuse box contains the electrical "weak link" in the circuits of a railway car equipment for the purpose of protection of the apparatus from overloads. Because of this weak link or safety valve, it is highly important that it be kept in the best of condition and ready for the emergency. The fuses must be properly selected and care taken in providing the proper capacity fuse for giving the protection desired.

It is not uncommon to hear of main fuses being kept at red heat continuously during accelerating periods throughout the day. When this is the case, it will usually be found that the fuse must be replaced quite often, not because of the motorman overloading the motors by improper notching nor because of continual faulty circuits, but because of the gradual decrease in capacity of the fuse due to "scaling" or oxidizing during the intermittant cooling and heating. This is usually more noticeable where low capacity fuses are required, because of the fuse cross-section being relatively small. Copper fuses are ordinarily used, but it has been found more satisfactory to use aluminum where trouble due to rapid oxidizing is noticeable. The aluminum does not scale and the naturally oxidized surface protects the metal from further oxidizing.

APPLICATION OF FUSES:

It is usual to install, in the trolley circuit of railway equipments, fuses of the same capacity in amperes as the combined hour rating of the motors. For instance, a quadruple equipment of 40 horse-power motors (one hour rating 73 amperes) is ordinarily supplied with a 300 ampere fuse.

TYPES AND ARRANGEMENT OF BLOWOUT:

For general railway work, the copper ribbon magnetic blowout type is standard. In the fuse boxes of the magnetic blowout type, the fuse itself is the source of blowout. The fuse is so located, with reference to magnetic parts built into or surrounding the box proper, that it forms a coil of one-half turn, and when carrying current sets up sufficient flux to extinguish the arc.

PERMISSIBLE RANGE OF FUSES FOR MAGNETIC BLOWOUT FUSE BOXES:

It is evident that the greater the current carried through the fuse circuit, the greater will be the flux for affording magnetic blowout. It may sometimes happen that a fuse box will blow a 500 ampere fuse more easily than a 100 ampere fuse, due to better magnetic blowout at the higher current. On this account it is usually a minimum, rather than a maximum size of fuse which limits the application of a given box of known continuous current carrying capacity. For the same reason, it is usually found that the more severe the short-circuit the more easily the fuse opens it.

CONTINUOUS CAPACITY:

On account of the intermittant character of the loads on railway equipments, the rated capacity of the fuses which must be installed is much greater than the equivalent continuous current that they must carry. For instance, in the case of quadruple equipments of 40 horse-power motors, a fuse rated at 300 amperes is ordinarily required. The equivalent current that the fuse box need be able to carry continuously, however, is approximately 200 amperes. On this account fuse boxes, for railway service, may be used with fuses rated to blow at currents considerably in excess of the continuous capacity of the box.

MOUNTING OF FUSE BOXES:

In mounting the fuse box under the car, it is usually a difficult matter to place it where wheel wash does not directly or indirectly strike the box, or where snow and water do not reach it in some way. For insulating purposes it is, therefore, desirable to use porcelain mounting bolt insulation.

One of the main points to be considered in locating the fuse box is the accessibility in making fuse replacements. Care should also be taken to have no air pipes, brake chains, or any other grounded part of the car equipment below or in front of the arc chute. As many fuses are at or near red heat during the time the car is in operation, a certain amount of ventilation must be provided the fuse box and vent holes are usually located in the top of the box for this purpose. During regular car inspection the vent holes should be inspected to see that these holes have not been plugged by dirt. The vent holes provided in the box are usually of little value when the fuse box is mounted directly to the car floor and, when mounting, the box should have a free space of at least three inches between the car floor and the top of the fuse box.

PLACING OF FUSES:

The fuses, which should be of the type designed by the manufacturer of the fuse box, should be clamped securely between the jaws; being careful that the full surface of the clamps hold the ends of the fuse securely. If the contact surface of the clamping jaw becomes pitted, this should be made smooth or the jaws replaced at the next regular car inspection, or sooner if the jaws are becoming overheated. The fuses should not be bent to irregular shapes in order to make them fit in the box between the jaws. The fuse should also be centrally located in the box and not come in contact with sides, as this effects the blowing point of the fuse. H. H. JOHNSTON

THE JOURNAL QUESTION BOX

OUR subscribers are invited to use this department as a means of securing [illegible] electrical and mechanical subjects. The topics should be [illegible] individual pieces of apparatus is not supplied. Care should be used to include all data necessary for an intelligent answer.

A PERSONAL reply is mailed to each questioner enclosing a stamped, self addressed envelope as soon as the necessary information can be obtained. Anonymous questions cannot be considered. As each question is answered by an expert on the subject involved, and checked by at least two others, a reasonable length of time should be allowed before expecting an answer.

1783—BOOSTER TRANSFORMER—Would it be practicable to step up the voltage on a two-phase line as shown in Fig. (a) and would the condition of the line be altered? G.L.K. (ALBERTA)

This scheme is entirely inoperative, as the secondary circuits are open for a

FIG. 1783(a)

load on either phase alone and the transformer connected to the inner lines of the secondary is a high impedance to a load between the outer lines. A single-phase booster should be used in each phase. J.F.P.

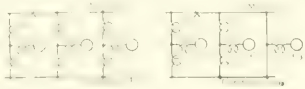
1784—INSULATION FOR UNDERGROUND CABLES—In designing a central station it is desired to run 2200 volt wires in steel conduit. What thickness and kind of insulation should be specified for these wires? Would the same insulation be suitable for installation (indoors) in fibre conduit? M.J.I. (D.C.)

Paper insulated lead covered cables are recommended for use on 2200 volt service in steel conduit in central station. The insulation may be varnished cambric or rubber, if desired, but this is more expensive and paper insulation has given good results in service. Lead covering is essential for paper insulations. The insulation may be varnished cambric or rubber, as conduits are likely to be damp and cause deterioration of a braided outer covering. All of the wires of the circuit must be in the same steel conduit. A multiple conductor, paper insulated lead covered cable should have about 4/32 inch thickness of paper insulation on each conductor and 4/32 inch thickness as a belt around all of the insulated wires just inside the lead sheath. This thickness of insulation is more than is used for 2200 volt service but it is important to have thoroughly good insulation in the central section in order to insure continuity of service. The same insulation may be used for installation indoors in fibre conduit. If lead covered cable is used, steel conduit is more often used than fibre conduit. D.H.

1785—LEAD GASKETS—When pouring hot lead into a mold to form boiler gaskets, we have a great deal of trouble in keeping them from separating, or at least cracking. Please let me know what the trouble is. J.H.B. (WYO.)

We understand that these gaskets are to be used on hand hole plates on tube headers. We have used this kind of gaskets on this location of the boiler and found very good success with them, where the surfaces of the headers and caps were not pitted, so that a perfectly smooth bearing could be obtained for the gasket, and of course this application was made when the headers were constructed of steel. With reference to the moulding of the gaskets, we have never tried this, as our gaskets were stamped from the sheet lead. We presume the trouble that has been experienced in the gaskets separating or cracking after the lead has cooled in the mould, is due to the contraction. Lead having very small tensile strength, the result would be that it would not hold together with sufficient strength to counteract the contraction pressure from within. We would suggest as a method to overcome this, that a split mould be used, fastened at the center either by slots or guides producing a very small amount of friction or else small pins to hold the mould in place when the lead is poured. The exertion of the contracting metal would be greater than the friction or pin resistance, and would allow the finished gasket to come out of the mould intact in the desired shape. O.H.B.

1786—SHORT-CIRCUIT CALCULATIONS—Am I correct in making the following short-circuit calculations? The reactances of the busses and generators are based on 30 000 k.v.a. The generators are each 30 000 k.v.a., three-phase, 25 cycles, 11 000 volts. Short-circuit in each case at mark X. In Fig. (a), the three-phase short-circuit current = 100 $\left(\frac{3}{[illegible] + 5}\right)$ 1575 = 31 500 amperes. In Fig. (b), with G_3 connected in without reactances



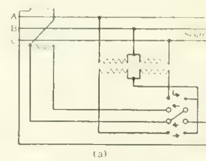
FIGS. 1786(a) and (b)

in the bus leads, the three-phase short-circuit current = 100 $\left([illegible] + \frac{[illegible]}{[illegible]}\right)$ 1575 = 31 200 amperes. E.L. (N.Y.)

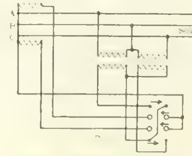
The results obtained by your formula are correct for the symmetrical value of the current but it should be borne in mind that at the instant of short-circuiting there is an initial surge of current that will approximate 58000 amperes due to the unsymmetrical position of the current with reference to the axis. If your calculation is for the application of bus-bars, they would have to be designed to withstand the strain due to this 58 000 r.m.s. amperes. As the short-circuit continues the value of the current dies down and at the end of 0.25 second the value is 22 000 amperes and at 0.5 second is only 18 000 on a three-phase short-circuit. If your calculation is for circuit breaker application, the current to be interrupted will depend upon the time required for tripping the circuit-breaker, being less the longer the time taken. In the case of a single-phase short-circuit the initial surge does not die off so rapidly, as for instance the current at the end of 0.25 second will be approximately 29 600 r.m.s. amperes. A complete discussion of this general problem will be found in an article on "Design and Selection of Oil Circuit Breakers" by Mr. J. N. Mahoney in the Journal for November, '10, p. 462. J.D.W.

1787—METER CONNECTIONS—Figs. (a) and (b) show connections of current and potential transformers to a three-phase watt-hour meter. Fig. (a) I understand will give the correct record for energy flowing in the circuit and Fig. (b) you will notice has one potential transformer reversed and the corresponding leads reversed at the meter. I believe this connection will not record the correct amount of energy flowing in the circuit. However, I cannot explain why reversing one potential transformer will make a meter register incorrectly while reversing one of the current transformers as in Fig. (a) will not affect the registering of the meter. Kindly explain. L.A.F. (MASS.)

If the meter in Fig. (a) is so connected internally that correct registration is obtained with the wiring diagram shown, then, Fig. (b) connection will give correct registration, since the instantaneous directions of the currents in the current and voltage wind-



(a)

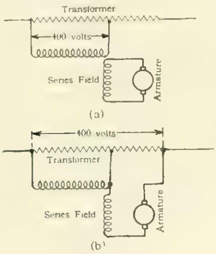


FIGS. 1787(a) and (b)

ings still have the same relation to each other. In diagram (b) the upper element has been shifted to lines A and B while the lower element has been shifted to lines B and C. To change the direction of rotation it would be necessary to reverse the series leads or the shunt leads of each element, but not both series and shunt leads. H.R.

1788—Single-phase Induction Motors—(a) Please tell how to calculate the full-load rotor current of a single-phase induction motor with squirrel-cage rotor, also with two or three-phase slip-ring rotors. Also please inform me how to calculate the no-load current and the starting torque with the machine arranged for starting with the split phase method. (b) Do you consider it possible to build a satisfactory single-phase series compensated motor for a 400 volt, 50 period circuit for an output of say 20 hp and full load speed of 1000 r.p.m. for crane or winch work. F.S.A. (ENGLAND)

(a) Calculations of induction motor characteristics are given in some detail, illustrated with examples, in an article on "Shop Testing of Induction Motors" published in the Journal for



Figs. 1788(a) and (b)

Feb., '14, p. 100 and continued in March '14, p. 178. This article includes the well-known circular diagram method of calculation, as well as Steinmetz symbolic method, and also the method proposed by Mr. W. J. Branson, which is especially advantageous in calculating single-phase motors and small polyphase motors. The Branson method which is summarized in this Journal article was presented in detail in the *Transactions of the A.I.E.E.* for July 1912, p. 1525. (b) It is possible to build a single-phase, 400 volt, 50 cycle, 20 hp., 1000 r.p.m. series motor either of the repulsion type, shown in Fig. (a) or of the transformer conduction type three-wire shown in Fig. (b). In this connection see articles on "Single-Phase Commutator Motors" by Messrs. R. E. Hellmund and J. V. Dobson in the Journal for March '16 p. 112 and by Mr. R. E. Hellmund in the Journal for Aug. '17, p. 322, Sept., '17, p. 363, and Oct. '17, p. 390 H.G.J.

1789—Wave Form of Generators—I was much interested in an article on "Wave Form of Electric Generators" in the Journal for Nov. '18, but was handicapped in understanding it by reason of the fact that I did not understand just what was responsible for the generation of the lower harmonics in such a machine. If you could explain this to me I would appreciate your favor very much. J.J.G. (N.Y.)

For the third or fifth harmonic to occur in the voltage wave form, it is necessary that these harmonics exist in the flux field form. The Journal article referred to, shows how to develop the voltage wave from a given field form and therefore the following will be confined to showing why harmonics occur in the field form. If it were possible to build an exciting winding distributed over the entire face of the rotor and to have the current in each conductor of such a field winding vary as a sine law, then the flux field form would have a sine shape and a voltage of only fundamental frequency would be developed in the armature winding. In practice, however, it is more feasible to build the winding on each pole in a single coil, as in a salient pole machine shown in Fig. (a). In a salient

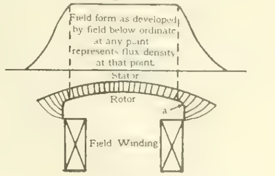


Fig. 1789(a)

pole machine, at no load the magnetomotive force is the same at every point on the face of the pole and the flux along the face of the pole therefore is inversely proportional to the length of the air-gap. The tips of the poles are generally rounded off at the point *a*, and consequently the flux density is constant along the pole and drops off at the ends as shown in Fig. (a). It is shown in various books on mathematics that such a curve is the sum of a fundamental sine curve and several higher multiples of the fundamental. In most field forms the lower harmonics are more prominent, and Fig. 1 in the Journal article referred to shows a field form which is composed of a fundamental and third harmonic. See "The Analysis of Periodic Waves" by L. W. Chubb in the Journal for Feb. and May, 1914 S.L.H.

1790—Expulsion Fuses—Please discuss application of expulsion fuses in the case shown in Fig. (a). Can the expulsion fuses safely rupture the short-circuit current? If not, please discuss primary protection for distributing transformers. What is the highest rupturing capacity usually obtainable in expulsion fuses. M.J.I. (D.C.)

Expulsion fuses have a rupturing capacity of approximately 1000 amperes at 7500 volts, when used one per wire, and proportionately greater or less cur-

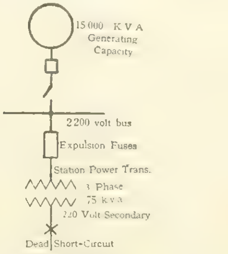


Fig. 1790(a)

rent rupturing capacities at lower or high voltages. This is approximately 7500 k.v.a. In the case in question, assume three-percent reactance in transformer, then from tables giving transformer characteristics we get 6560 amperes as the short-circuit current on the secondary side of the transformer, which would be about 1450 k.v.a. which the fuse would have to rupture. This is well below the maximum rupturing capacity of the fuse. F.B.K.

1791—Meter Connections—A wiring diagram of a method which we are using for metering with the same 3-phase watthour meter both 3-phase and single-phase lighting load is shown in Fig. (a). Is this method correct? We have been unable to find any error in it. L.E.B. (OHIO)

The meter connection shown in Fig. (a) is correct for measuring three-phase power, and will correctly measure the lighting load if the circuits are exactly balanced. If the light circuit which is connected between the middle wire of the three-phase circuit and the single-phase, three-wire neutral carries a greater load than the other side of the circuit the excess load will not be measured. On the other hand, if the single-phase lighting circuit which is connected between the outside wire of

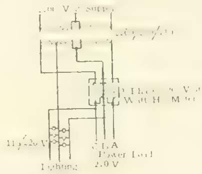


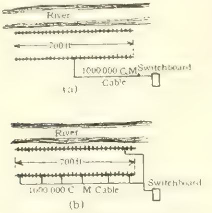
Fig. 1791(a)

the three-phase and the three-wire single-phase neutral carries a greater load than the other circuit, the wattmeter registration will be too great by the amount of this difference in load, as it will register the excess load on both sides of the three-wire circuit instead of only on one side. As connected, the wattmeter will require the customer to pay for the losses in the potential coil of the wattmeter. We believe it is generally customary for the central station to stand these losses and most wattmeters are so connected at the factory. However, the difference in this case is trifling, but there will be a serious error in the registration of the single-phase load if it is much unbalanced. C.R.R.

1792—Grounding Coal Rig—We have on our dock two coal rigs both using 1150 hp. There is arcing on the cables and clam when they come in contact with a boat. Is that because there is not a good ground? The rails are bonded on one side and grounded to a 1 000 000 circ. mil cable. The rails are 700 feet long and are grounded about in the center as shown in Fig. (a). The lights get dim and there is a drop in voltage when the rigs are running. Would I get better results by grounding the two rails and running a ground cable the length of one rail and ground from it every 40 ft., as shown in Fig. (b). A.R. (WISC.)

No voltage is stated, but we have assumed that 230 volts direct-current is the voltage used. It would seem that 1150 hp per rig is too large and that probably 1150 amperes per rig would be more reasonable. On the basis of 1150 hp, the drop in 350 feet in 1 000 000 circ. mil cable would be approximately 30 volts and in case the rigs were near the

ends of the track, the drop in the track itself would be more than this amount. This voltage drop would account for the dimming of the lights and for the sparks between the cables or clams and the boats. Bonding of both rails and the addition of a second 1 000 000 circ. mil cable to the rail, which is not now grounded, would improve the voltage conditions considerably and probably



FIGS. 1792(a) and (b)

eliminate to a large extent the sparking which is now experienced. Inasmuch as the distance is relatively short, it would be easy to run a small wire from one rail to the other temporarily or from either or both rails to the switchboard and measure the voltage drop with a low-reading voltimeter. Similarly voltage readings from the bucket to the ships could be made. Such readings will indicate the best remedy. W.A.C.

1793—Use of Synchronous Condenser—We are operating a number of 2300 and 440 volt induction motors at a lagging power-factor of about 60 percent. We receive the power over a 33 mile transmission line and purchase it on a k.v.a. basis, at an arbitrary power-factor of 90 percent. Our peak demand is 145 amperes on a chart-drawing ammeter connected in one side of three-phase line. By using one of our emergency 200 kw generators as a synchronous condenser, we are able to raise our line voltage to normal and reduce our demand on the power company to 105 amperes at peak load. This requires rheostat adjustment the same as where the machine is operated as a generator, delivering 40 amperes to the line, synchronized with the power company. The indicating wattmeter registers nothing. The recording wattmeter records about the same as when operating as a generator. Can you suggest any changes in the operation of this machine and why? Can we take mechanical power, belted from this condenser more efficiently than direct from the lines? Where should the power-factor indicator be located, in the power company's substation or in one plant near center of distribution, or the condenser panel using the present switchboard instrument transformers? H.H.H. (WASH.)

The use of a synchronous condenser at your plant does two things. It raises the power-factor of the total load drawn from the line and it also raises the voltage at your plant. These effects both tend to reduce the current drawn from the line although it does not reduce the actual kw used. If the indicating and recording wattmeters you refer to are both connected to show input to the synchronous motor, they should both read the same. If the motor is delivering no mechanical power, these meters will record the losses of the motor only. Probably one is not correctly connected. The power-factor indicator should be located at your plant at the incoming line. If your synchronous condenser is not fully loaded (rated amperes) when the field is adjusted so as to give suitable power-factor on incoming lines you can belt it up for mechanical power sufficient to bring it up to rated load. W.R.W.

1794—Starting Synchronous Motor—A synchronous motor of 258 k.v.a. driving a 1600 foot air compresser is started by a compensator with 3900 primary volts and 1755 to 2535 secondary volts. It takes about thirty seconds before the compensator is cut out. The middle coil of three, burnt open and I do not have a spare one. Should there be some way to start the motor under these conditions? H.S.B. (PA.)

The motor can probably be started by short-circuiting the open coil and connecting the two remaining legs of the starting transformer in *V*. as shown in Fig. (a) Q.G.

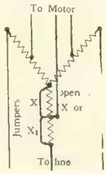


FIG. 1794(a)

1795—Direction of Rotation of Rotary Converter—What changes are necessary to reverse the direction of rotation of a converter connected two-phase on the high-tension side of the transformer, and six-phase double-delta at the converter; also two-phase to six-phase diametrical at the converter. Assuming that a commutating pole, compound wound converter operated in a clock wise direction, what will be the effect on commutation if the direction of rotation is changed, also if the converter builds up in the wrong direction. G.M. (N.Y.)

With a two-phase primary, it would be possible, by means of two tee connections of the secondary windings, to have a double delta connection on the rotary converter However, with a two-phase primary, it would not be possible (without the use of an additional transformer) to have a dimetrical connection on the converter, as ordinarily spoken of. By tying the middle points of the teaser of each tee together (assuming 100 percent of the teaser leg wound) a connection is obtained which might be construed as a diametrical connection. In any event, the direction of rotation of the converter may be reversed by reversing either one (and only one) of the two primary phases. The direct-current brushes on a converter are set at a certain angle on the commutator, with respect to the direction of rotation (usually against the direction of rotation, if the angle is large or with the direction of rotation if the angle is small) so as to give the least vibration, and hence the best commutation. If the direction of the rotation is reversed, the brushes are liable to chatter and impair the commutation. However, except for such mechanical difficulties as these, which may be encountered, a commutating pole compound wound converter should commutate about as well when running in one direction as another. If the converter builds up its voltage in the wrong direction, it will not affect commutation. If, as is usually the case, it is necessary to maintain the same polarity, it will be necessary to slip a pole, by means of a field reversing switch, or by opening the alternating current switch, to make it come up with the right polarity. M.W.S.

1796—Series Transformers for Constant Current Systems—We have a street lighting system, consisting of cast-iron post, lead and armoured single and duplex cable, operating at approximately 2400 volts, 6.6 amperes, alternating-current, (constant current system) with series transformers in the base of each lighting post. For the purpose of saving energy we desire to turn off a certain number of lights each night and for this purpose we installed a 10 ampere, snap switch in each pole which shorted the secondaries of each transformer. Although over half of the lamps were turned off at midnight the meter showed practically no reduction in energy consumption and we assumed our saving would be about 25 percent. Will you kindly inform us the difference in energy consumed by a current transformer (street lighting type) with secondary shorted? With secondary open? Also energy consumed by the transformer when operating under normal condition with lamp burning. W.F.H. (CAL.)

Considerable saving should be accomplished by short-circuiting the series transformers. The losses in a transformer suitable for supplying a 300 watt lamp are approximately as follows:—

Secondary open circuited.....30 watts
Secondary short-circuited ....17 watts
When supplying normal load 25 watts

J.F.P.

1797—Insulation of Magnetism—I would be glad to know whether lines of force (electrical magnetism) can be positively insulated excepting with air. Can you advise what materials would completely insulate the sides of a moving plunger from the lines of force of a powerful solenoid magnet? E.A.R. (N.J.)

There is no known material which will insulate lines of force better than air. Materials which have a lower permeability than air are known as "diamagnetic". Bismuth shows this characteristic to a greater extent than any other common material but its permeability is only very slightly less than that of air, so that any improvement due to its insulating quantities may be considered negligible as compared with air. The only practicable method of isolating apparatus from magnetic lines of force is to shunt the apparatus with a very good conductor of magnetism. As an analogous case an easy way of keeping the current in an electrical circuit out of an ammeter is to shunt the ammeter with a very low resistance, in which case practically no current will flow through the instrument. Similarly the only practical way to isolate your plunger from lines of force is to surround it with a heavy steel box, in which case the lines of force will go through the steel and almost none at all through the plunger. This is a standard method of eliminating the effects of stray magnetic fields upon measuring instruments. C.R.R.

1798—SHAFT CURRENTS—Can you give me an explanation as to the cause of "shaft currents in machines"? In what types of machines is this likely to occur and does the density at which the iron is worked have any thing to do with it? H.L.S. (ALA.)

Since in rotating electric machines the shaft, bearings, bearing supports, and base form a closed electric circuit, it is obvious from the elementary laws of electricity and magnetism that currents will tend to circulate in this closed circuit if, (a) the flux interlinking the shaft or any part of the circuit varies, or (b) the shaft rotates in a magnetic field which is at right angles to its axis, or has a component at right angles to it. The variation of the flux interlinking the shaft is usually caused by dissymmetry in the reluctance of the parallel magnetic paths of the armature, for different positions of the field poles. For instance, if the armature of a two-pole machine is built up of segments so that there are three equally spaced air-gaps, a_0, b_0, and c_0, and the gap a_0 coincides with the center line of the pole, as shown in Fig. (a), the flux passing across each side of the armature must cross one gap. Consequently it will divide equally between the two parallel paths. However, when the armature has rotated so that the gaps are in position $a_1b_1c_1$, more flux will pass down the left hand side than on the right

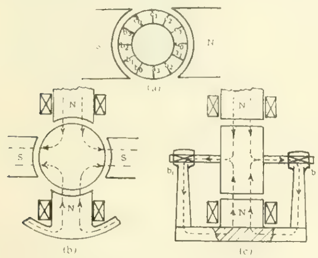


FIG. 1798(a), (b) and (c)

hand side, for it has only one gap, while the right hand side has the two gaps a_1,b_1 in series. When the air-gaps are in positions a_2, b_2, c_2, the flux will again divide equally between the two paths. However, at position a_3, b_3, c_3 the gaps b_3 and c_3 are in series on the left hand side and the greater proportion of the flux passes down the right hand side. From the above it is evident that with this pole segment combination the flux is alternately weak and strong on the different sides of the shaft as the armature rotates, This action is equivalent to a periodic swinging of the flux across the shaft. The swinging flux induces a voltage in the shaft which tends to circulate current around the closed electric circuit. In this case, if the iron is saturated the reluctance of each of the magnetic circuits is materially increased and the percentage of dissymmetry due to the segment-air-gaps for different armature positions is smaller, so that the amount of flux swinging across the shaft should be reduced. Shaft currents due to the second cause are usually common to machines which have unsymmetrical windings. The most pronounced example of this is the consequent pole type of machine, in which only one-half of the field poles are equipped with field coils. With this type of machine, the flux, leaving the wound field poles is free to return by two parallel paths, one across the air-gaps to the south poles as shown in Fig. (b), and the other across one gap through shaft, bearings, pedestals base and frame as shown in Fig. (c). The actual division of flux between the two paths depends upon their relative reluctances. The rotating shaft in the magnetic field at b and b_1, produces a voltage which tends to circulate current in the bearings from one end to the other. C.M.L.

1799—STARTING COMPENSATOR — Please give some information on a three-phase 2300 volt, three-wire star connected compensator or starting transformer connected as shown in Fig. (a). The primary voltage is 2300 and there are taps on the transformer, varying from 640 to 960 volts secondary. The 530 hp. is used to start a 500 kw direct-current motor generator set. We use a three-pole, three-phase, double-throw oil switch to start and every once in a while when starting the operator has a blow out, or explosion in the oil switch when he switches around from starting to running and this three-phase transformer starter has burned out several times. I blame the operator for changing his switches around too fast not giving the starting side time to break the arc on the contacts. Then when the running side is connected, it backs the primary current through the switch to the secondary side of transformer which causes bucking in the coils, which I found stripped off the core and jammed up against the iron of the transformer. F.A.B. (PA.)

If the running switch can be closed when there is current still flowing through the starting switch, there is always the possibility of the trouble as described. The mechanical interlock between the starting and running switch should provide protection from this trouble and we suggest that the perfor-

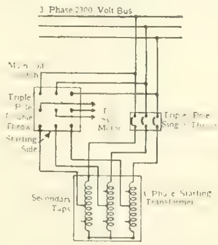


FIG. 1799(a)

mance of this interlock be checked. Another possible source of this trouble may be within the transformer. The coils may not be sufficiently braced mechanically to withstand the strains caused by its own magnetic field. G.W.H.

1800—WINDAGE OF ROTARY CONVERTER—What percent of the kw rating of a 60 cycle, 500 kw, 250 volt, direct-current, 1200 r.p.m. rotary converter is absorbed by windage alone, at 1200 r.p.m.? I wish to know what size motor to use to drive it to grind the commutator but also would like windage separate, the friction without brushes is negligible. J.E.MCH. (MICH.)

The bearing friction and windage of the above converter at 1200 r.p.m. is approximately 5.5 kilowatts (exclusive of brush friction). Assuming the grinding stone has a surface of three square inches (in case two stones are used), a maximum pressure of 10 pounds per square inch, and a maximum coefficient of friction of 1, approximately 3.5 kilowatts would be consumed by the grinding tool at a speed of 1200 r.p.m. Therefore, a 12 horse-power motor should be ample for grinding the commutator at a speed of 1200 r.p.m. However, a motor of this size will probably not be sufficient to start the machine from rest. It will probably be most convenient to start the machine in the ordinary manner, and then cut the power off and let the motor run the machine. M.W.S.

1801—EFFECT OF FLUCTUATING CURRENT ON LEAD STORAGE CELLS—Does a varying current, such as is derived from a tungar rectifier or generator driven by hit and miss gasoline engine, used for charging lead cells, cause depreciation of these cells, due to the fact that the current varies in the above manner? M.C. (S.C.)

Varying current, such as is obtained from a tungar rectifier, or other device that does not give a smooth direct current, will do no harm to a lead storage battery, providing the current is not large enough to cause excessive heating. The mere fact that the current varies does not in itself do any harm, but it is a fact that the heating value of this kind of current is considerably higher than that of smooth direct current of the same average value as shown on a permanent magnet ammeter. The alternating current has a root-mean-square or effective heating value about twice as great as that of a smooth direct current equal to the average value shown on the direct-current ammeter. It is, therefore, entirely possible to overheat a battery when charging from such a source, even though the current, as shown on the meter, is not above the value specified for the battery in question. In actual practice, however, trouble rarely occurs, because most half wave rectifiers deliver currents sufficiently low so that no trouble occurs when charging batteries of the size customarily used nowadays for automobile lighting and starting. In the case of the generator driven by hit and miss gasoline engine, the larger current will be counterbalanced by the fact that the variations in the current are much smaller than in the half wave rectifiers. In general, if care is taken to prevent the temperature of the battery from rising above the value allowed by the manufacturer, no harm will be done while charging from any of the above sources. In addition a battery must not be caused to gas violently at any time during the charging period, even though the temperature of the electrolyte may not exceed that specified as a maximum by the battery manufacturer. The process of charging a battery is purely an electro-chemical absorption of energy. The active materials of the battery plates have a capacity at any given time to absorb only a very specific amount of electrical energy. If at any time the electrical energy is applied to the plates in such a quantity that all of it is not absorbed in the desired manner, the

electrolyte will be caused to gas more or less violently, depending upon the amount of the excess energy applied. This gassing is simply the electrolysis of the water of the electrolyte, namely, breaking up of water into two gases, hydrogen and oxygen which when forming produces an explosive action tending to tear off particles of the active material of which the plates are composed. If a rectifier of the tungar type produces peak current values materially in excess of the current which the battery can absorb, undue gassing of the battery will take place, even though the current is not sufficiently high to produce undesirable heating of the electrolyte. In our opinion, most of such rectifiers are commercially satisfactory, in that either the peak currents are not sufficiently high to do any damage or not of sufficient duration to materially decrease the life of the battery. In so far as current variations in the case of gas engines driven generators are concerned, we doubt seriously if any damage will be incurred by current peaks. The damage usually encountered with this type of equipment is that of reversal of battery current through the generator when the engine speed decreases below normal.

[illegible] and A.M.S.

1802—Electric Furnaces—I have been reading with considerable interest the articles in your Journal and elsewhere concerning the development of the electric furnace for steel manufacture, and am now interesting myself in the question as to whether the electrical furnace could not be applied with equal success for the melting and manufacture of glass. Naturally the induction type of furnace suggests itself, but I will be obliged if you could provide me with information concerning this subject, and the difficulties that may have to be faced by applying the electrical furnace for this purpose; also whether any benefit would come in increased fluidity, as a result of higher temperatures which are possible by the use of this type of furnace. Are electrical furnaces employed and manufactured for this purpose, if not, could they be? I will be pleased if you would give me references to information on the subject in detail and furthermore, benefit may come if you could refer my query to firms who are particularly interested in this subject from other than the electrical side.

[illegible]

The subject of electric glass furnaces is one of the most inviting ones yet awaiting practical development in the electric furnace field. The electric furnace can undoubtedly be applied with even greater success for glass melting and refining than for the manufacture of steel. Naturally the induction type of furnace does not suggest itself as practicable for the reason that glass when cold is nonconductive and the furnace would necessarily have to be heated from the outside in starting it. There have been many patents taken out both in America and Europe on electric glass furnaces. A number of inventors have considered the scheme of using the molten glass as a resistor. Others have used the radiant heat from the arc. The difficulties have been with the refractories and with the contamination of the glass charge. As the electric heat is so much more intense and applied directly to the molten glass, there is a very great advantage in the rapidity with which the glass may be melted and refined and the increased fluidity. Electric furnaces are not employed, so far as is known, in practical glass manufacture although one concern in Pittsburgh is working actively on this problem. In our opinion they certainly can be and will shortly be so used. The latest information on the subject is to be found in the patent files. W.E.M.

[illegible] In a direct-current motor having poles set radial and horizontal is it always the rule in rewinding armature to bring short bottom lead out straight and give long lead throw to right when facing commutator? If short lead is given throw either way please explain why. M.S.B. (PA.)

There is no method of bringing out the leads from the armature coil and connecting them to the commutator that is always used. The leads are given a throw of different distances on different motors. It is often advantageous to give both armature leads a throw. Changing the throw may give a coil a better shape or a more desirable brush position. Consider this particular case. If the short lead was lengthened and the other shortened, and the short lead given a throw to the left while the throw of the long lead was shortened enough to keep the distance between where the two leads are connected to the commutator constant, then it is evident that the coil would be more nearly symmetrical in shape. During at least part of the time a coil is commutating the bar to which an armature coil lead connects is under the brush. To get good commutation an armature coil should have its conductors lying in a slot about halfway between the main poles, during commutation, then, in the motor mentioned, the brush rigging must be made to hold the brush on the commutator at a point about halfway between the main poles, since that is where the coil side is when it commutates, and the lead comes straight out. In some cases it might be desirable to have the brush in this position because of mechanical reasons. The machine may be so constructed that there is not room to put the brush in this position, that place may be inconvenient for inspection and replacement of carbons, or the brushholder rigging for that position may be more expensive than for another position of brush. Assume that it is found that the most desirable place for the carbon brushes is in line with the center of the main poles instead of half way between. Because of commutating conditions, as previously given, the coil with sides halfway between main poles must have a lead from one side connected to a bar under the brush. Then the lead must, to get this brush position, have a throw reaching from half way between poles, to the center of a pole. Due to the de[illegible] rigging varying on different motors, the brushes are placed in different positions on the commutator and it is necessary to connect the leads in different ways. M.S.H.

[illegible] Slots—What advantage is gained from making the core of a small induction motor with partially inclosed slots? To what extent would the operation of the motor be changed by filing out the slots and winding with taped coils? E.C.C. (MINN.)

Partially closed slots are a decided advantage, from the standpoint of electrical performance, but are difficult to wind and insulate, so are generally used only on the small machines. In a general way the output of a motor is a function of the current capacity of the copper and the magnetic flux in the airgap. The flux depends upon the magnetic reluctance which is an inverse function of the tooth tip area. Thus, the effect of filing out the slots will be a smaller tooth tip area and a higher reluctance. In order to obtain the same flux a higher magnetizing current will be required, thus greatly reducing the power-factor and increasing the copper losses. The surface iron loss due to the slot openings will also be increased to a considerable extent, so that the total increase in losses may cause the motor to run excessively hot. H.L.S.

1805—Self-Starting Synchronous Motor—We took a 90 kw, old style Westinghouse, revolving armature type generator marked 2200 volt, 2 phase, 60 cycle, 720 r.p.m., and installed a squirrel-cage winding on the field, by putting in lengthwise across the field, three slots, and putting in these slots $\frac{3}{16}$ copper bars, joining on the end with an end ring, consisting of $\frac{1}{8}$ by 2 inch copper bar,—with the idea of making a synchronous self-starting motor, in order to start a belted generator. With the construction above, we are experiencing considerable trouble in starting, and we would like to inquire what means to take to increase the starting torque, which at the present time is not sufficient to turn the motor over light, without any belt. The armature has a closed winding. Do you think that the starting torque can be increased by changing this winding to series star? G.P.E. (N.J.)

The starting torque of the motor will be increased by applying a higher starting voltage. This will increase the current during starting which may not be desirable if it is fairly high already. Another means of increasing the torque is to make the starting winding of higher resistance. This can be accomplished by using brass in place of copper for the bars or end rings, or by making the end rings of much smaller section. Such a change will probably reduce the starting current and at the same time increase the starting torque. Q.G.

[illegible] Banding Wire—What is the tensile strength and composition of armature banding wire? What is the strain in the wire for narrow size wires while banding and what is the method most frequently used to obtain the strain? A.H.B. (D.C.)

Steel banding wire may be of the hard grade with tensile strength of 200 000 lbs. per square inch or more or it may be of the soft grade with tensile strength of 140 000 to 180 000 lbs. per sq. in. The strain in the wire while banding will vary with different applications but must be below the true elastic limit of the wire. The strain is applied to the wire either by means of proper spring clamps or by passing the wire around a stick to give the strain found necessary to force the work into position and hold it. Various methods of applying this tension and the amount of tension which is desirable for railway motors are given in "Railway Operating Data" page for April 1917. p. 168. T.D.L.

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The Street Railway Situation

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AMONG the many problems which are now before the American people for solution, that of the electric railways is not the least. Here we have an industry which performs an essential service for the people and in which some six billion dollars of the peoples money is invested, already in the breakers and fast drifting upon the rocks of financial and physical ruin. It is evident that the wreck cannot be prevented by those who man the vessel—owners and managers—unassisted; that if the disaster is to be prevented help must come from those upon the shore —the public.

JOHN H. PARDEE

In such a situation two questions immediately suggest themselves, first, is the industry worth saving and second, if so, how can the salvation be accomplished. The matter has gotten itself far beyond the point where it is sufficient answer to say that the railways are but reaping the harvest of past iniquities. If this were so—and since there is ample proof that the industry as a whole has never charged an unreasonably high fare or received an unreasonably high return, such a statement may well be disputed—it would not in the least settle the problem, because from the public's standpoint the question is not one which concerns alone the capital already invested. If that were punished to the point of actual confiscation, the problem would still be unsettled, since to furnish the character and extent of service which the public requires, a continuous supply of new capital is needed, to obtain which the public must bid, with the amount of return and certainty of return as the influencing inducements.

The public may not, then, brush aside this traction question as one which concerns the companies alone, leaving them to sink or swim, as the hazard of fortune may decide. Unless it finds that electric railway service is no longer essential, it must work together with the managers to find a way out of the present threatening situation, because there is but one possible reason for suggesting that the day of usefulness for the electric railway is past and that is the advent and development of the automobile. But the fact is that despite the coming of the motor car, the electric railway is still necessary to the life of all communities of any size. The motor bus can furnish neither as good service, as dependable service nor as cheap service.

The development of our cities has been predicated upon the corresponding and responsive development of their street railway service and, as far as can be judged from the present state of the art, there is nothing to justify any prediction that the motor car will in the future be able to take the place of the electric railway.

The conclusion is irresistable that, although its functions may be modified and the extent of its activities limited by the motor vehicle, the urban railway (the interurban problem is a different one) must still be maintained and extended, if the cities of the United States are to be developed along the lines of the past, that is with the elimination of congestion and its accompaniments of squalor, ill health and immorality.

Before it is possible to consider a remedy for present day conditions, it is desirable to examine into the causes of which the conditions are the result. There is evidently one predominate cause that overshadows all the others. It is the decreased purchasing power of the fare received. According to the best informed economists, it is half what it was in 1914 and one third of what it was in 1896. If it could at once be restored to what it was at the earlier of these dates, the electric railway problem, that is the question of averting actual ruin, would at once dissolve. No such solution however, is, possible. The permanency of the present price level seems to be assured. Government banking and business agencies have accepted it and are busy at the work of readjusting their activities to meet the new conditions.

Primarily the task confronting the electric railways and the public interested in their activities is similarly to readjust their conditions. In this case, however, there have been interjected into the readjustment complexities and difficulties from which business other than under public control is free. These arise in the first instance from the fact that the industry is engaged in the most difficult of all public services. All other functions performed directly by the communities or delegated to private agencies are simple and easy of performance compared to it. Perfect and perhaps even universally satisfactory service is not, and from the very nature of things, cannot be given. To the mind of the individual, local transportation service will be entirely satisfactory only when it is prepared to transport him from the place where he is to the place where he wishes to be, at such times and in such a way as he may desire. The

amount and character of service demanded is constantly changing, so that it is obviously impossible under any circumstances, to meet these demands fully and, as a consequence, no matter how good, compared to reasonable standards, the service furnished may be, a large enough portion of any community is always dissatisfied to keep the street railway situation in a turmoil, to furnish fruitful soil for agitation and to create advocates for any suggested plan for improvement or theories of control and regulation. With other utilities, the establishment of satisfactory standards of service is entirely feasible. With the street railways it is not, and so street railways are under constant attack, in which every weapon, past sins and present delinquencies are seized upon to smite them.

There are three chief factors in the problem of readjustment which faces the industry; the new price level, labor and the competition of the automobile. If the enterprise is to continue without public subsidy, fares must be increased to meet the new costs; some satisfactory arrangement must be made with labor so as to eliminate strikes, insure efficient service on the part of employes and provide fair but not exorbitant wages, and the functions performed by the traction companies readjusted with a view to the part played in local transportation by the privately-owned automobile.

None of these things can be brought about without public co-operation and the task which confronts the industry today is, as I view it, to obtain this co-operation. The appointment of the President's Commission on Electric Railways is a tremendous step forward and is altogether the most helpful thing that could have happened in the present crisis. This Commission, removed from local influences and local prejudices has heard more than 100 witnesses from all parts of the United States and representing all of the various interests affected. Through its proceedings widespread publicity has been given to the situation and the public all over the country has been awakened to the fact that the difficulties with which the local companies are confronted are not peculiar to any particular locality but are simply a localized manifestation of a nation-wide crisis. Moreover, and this is the most important accomplishment, editorial comment, of which there has been a large amount, indicates a very much better understanding, both of the prevailing conditions and of the underlying principles that should govern the relations between communities and transportation utilities.

That these are after all much simpler than might be imagined can be judged from the singular unanimity of opinion expressed by the witnesses before the Commission. These included ardent advocates of public ownership, of public subsidy, of control and regulation by State Commissions and directly by the communities, of zone fares and of flat fares and of motor bus transportation, but it is not too much to say that all, or nearly all, would subscribe to the following statements as embodying their basic ideas of the relations that should exist

1—That private enterprise engaged in the business of local transportation is acting as the agent of the public in performing a public service.

2—That if it is to continue to perform such service it must receive such a return as will attract a continuous flow of new capital.

3—That such a return should be as regulated by the cost of money; i. e., that it should be high enough to insure new capital and no higher.

4—That to provide at all times such a return, fares should be flexible so as to respond to the variations in the cost of providing the service.

5—That with return limited and assured, taxes, imposts and other burdens assessed against traction companies are in fact levied against the car rider and should be adjusted on a basis of equity and justice as between the car rider and the taxpayer.

6—That the co-operation of the public in all measures looking towards economy in operation is necessary to cheap and efficient service.

7—That as a preliminary to any permanent plan of readjustment, a determination by a competent tribunal of the amount upon which a return shall be allowed to the owners of the private enterprise is necessary.

The question of public ownership does not enter into this recital of principles. Discussion of its merits would, for a large part of the country be entirely academic. With no American experience to serve as a guide and with widely different conditions in countries where it is in vogue, the merits of public ownership of traction systems in the United States is largely a matter of pure speculation. Moreover, it appears that only a comparatively few communities are in a financial or legal position to own and operate their utilities and that in fewer still is there any public sentiment for public ownership, so that as a cure for the present acute malady that confronts the industry public ownership offers no relief.

We can expect from the report of the President's Commission a clarification of the electric railway situation. As a guide both to the communities and the companies in their study of local conditions it will be of the greatest possible value. Underlying principles can be set forth that will materially assist and I have faith that the dawn of a new day for the industry is upon us. The Commission is unusually fair and unusually able. It represents first of all the public, the interest of which is the largest, and then it represents the local communities, labor, investors and operators. A unanimous report from such a commission will not only carry weight with the public, but will be proof that the interests involved are not so divergent that they cannot get together on a common ground for the common good.

The Stability of the Electric Street Railway Industry

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IT IS PROPER to apply the word "industry" to the street railway business. An industry is any branch or department of art, occupation or business employing large labor and capital. The present use of the word came naturally from the meaning of the simple noun, which means diligence, assiduity, perseverance, activity. These exactly describe the life of any true

industry. We must all admit that to make a success of the street railway industry requires the application of these qualities to a very high degree. An industry to be a true industry, must be stable. Stability is the quality of being firmly established. From the standpoint of stability are we justified in calling the electric railway business an industry?

The industry is so large, is so much in evidence in our daily life, that it appears to be a stable one. It has capital invested to the amount of at least $6 000 000 000; it has nearly 300 000 employees; it operates nearly 100 000 motor cars, and probably directly serves more than one-half of our whole population. There are many indications, however, that it is not, nor ever has been, truly stabilized. Money has been made in it and by it, but making money in itself does not constitute stability. Something more is needed. The main characteristics of a stable industry may be included under four subjects; namely:—

1—Sufficient capital and well-established and continuous sources of additional capital.

2—Sufficient number of skilled and contented employees.

3—A sufficient number of satisfied customers.

4—Men guiding its activities who have a proper conception of the above and are willing and able to correlate the three elements.

Without discussing the above points in detail, the following general remarks may help to a clearer understanding of what is now taking place in this industry, in which we are all so vitally interested. It has seemed to many that the street railway industry would be overthrown and would perhaps disappear. Some have thought and said that the day of the electric street railway was over, that other means of transportation of people in our cities would replace the electric railway. The industry has been in such a condition that it has been difficult to maintain a proper perspective. Many men in the industry have lost their proper point of view. They are discouraged and do not realize the possibilities of the industry if it could function under the proper conditions. The success of the industry in the future will depend largely on those engaged in it having a proper perspective of the industry, and a faith in its usefulness, possibilities and stability. If we feel that our business is fundamentally a failure and does not fit its environment, we will lose interest and the industry will fail. The industry will be improved and maintained in an improving condition only by men who believe in it and who have not lost their interest, and men who have faith in their own work and the possibilities of their own industry.

So far, the street railway industry has never been a truly stabilized business. No business is stabilized until all parties connected with it and served by it—capital, labor, officers and public—realize and see the fundamental relationship of that business to its environment. The history of most businesses is very similar. First the pioneer and exploiter conceive a business and operate it for some time. They often have very considerable success, from a money-making standpoint. The point of view of the pioneer and exploiter is to charge all the traffic will bear and do as little as possible in return, and he has no true conception of a real business. Their point of view does not contain the elements of true success and stability. The opportunities for so handling a business go by and a sense of the obligations of the industry to its customers finally reach those in charge—then only is begun to be developed the true place of the business in the general activity of the country; then comes true success and stability.

The sub-foundation of a successful business lies in a group of satisfied customers. We need plants, we need capital, we need men, but these do not make a business. We have a business that is a real one, a successful one, and a stable one, only when it is serving satisfied customers. This group of satisfied customers is the real foundation of an industry. The whole industry is built up on the goodwill of those whom it serves, for from them come the revenues which keep the whole industry running. They are the source of all of the life blood of the industry. The whole reason for the industry is to serve them, and in serving lies its true success.

It is apparent thus that the electric railway business has never been truly stabilized. What evidence is there that it can and will become stabilized?

1—It has a large amount of invested capital and employs large numbers of men, and should be, therefore, a true industry.

2—It is national in character, operating in nearly all communities throughout the whole country. It is neither North, South, East nor West; it is found everywhere.

3—It is a vital part of the everyday life and activity of these communities. A city cannot function, grow, develop, carry on its church, school or industrial life successfully without adequate and liberal transportation. All of these people are vitally interested in the railway business. This is due to a greater extent in this industry than in almost any other—it is a vital part of our daily life.

4—There is no known means of transporting large numbers of people on our streets as cheaply, as rapidly and as comfortably as does the electric street railway. Other means have their places, but on the average none of them can compete with the electric railway. The bus, the truck, the pleasure car, the horse and the wheelbarrow all have their places in transportation, but no one can conceive any of them taking the place of the electric railway.

5—To anyone in touch with the undercurrents of the electric railway industry it is apparent that they are beginning to realize the above to a greater extent than ever before. The industry is entering upon a stage of being stabilized. The people, who are the customers, are seeing that the railway is their concern and they are coming forward with help and interest. The operators are making their real object in life the service to the

public. Capital, seeing the people and the operators getting together, is coming to see that the business is capable of being stabilized, and it will, therefore, be a reliable and safe field for investment. There is a spirit of understanding and a feeling of helpfulness growing every day between the operators, the public and their representatives, and capital. When this is fully developed then will come the time when we can all take a pride in the railway business and it will be a stable field for the activities of the employees, the investment of capital, and the public will be satisfied with the service.

I have just had the pleasure of, and have derived great profit from, reading the proofs of some of the articles appearing in this issue of the JOURNAL. These seem to be the most hopeful that I have run across. They merit very careful reading by all. I refer to the contribution written by Messrs. J. H. Pardee, Theodore P. Shonts, L. S. Storrs, A. W. Thompson, Calvert Townley, Thos. S. Wheelwright, Luke C. Bradley, A. M. Lynn, B. E. Tilton, F. W. Hild, N. W. Storer, F. G. Buffee, Edwin Gruhl and E. D. Dreyfus. These articles were written by six presidents, one vice president, two assistants to president, two district managers, two general managers and one superintendent. These are surely representative men of the electric railway industry. Their thoughts certainly reflect the spirit which is abroad in the industry. After reading them let us ask the questions—How do they feel? What spirit inspires them? Have they courage? Are they looking forward and not backward? No one can read these most valuable articles without realizing that here are men who are not discouraged; here are men who are hopeful—who see the possibilities in the industry. It is most significant that running through all they have to say is the idea of better service to the public. This means that the industry is on its way to the position of having satisfied customers—the true basis of a stable business.

Public Understanding, Consideration and Appreciation Necessary for a Solution of the Electric Railway Problem

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THERE can be no permanent "solution" of the electric railway problem in the United States (or elsewhere) without a realization by the public that the problems of the industry are the problems of the public. To bring about this realization is the first duty of the industry, and gratifying progress is being made in that direction. Transportation is as necessary for the maintenance of life as air and water. Make it impossible to transport commodities from one place to another, and you make it impossible for humanity today to exist. Make it impossible or extraordinarily difficult, to transport individuals from one place to another, and you check human progress. Obversely, make it easy to ship goods and you improve the condition of mankind, you create business and contribute to the public's comfort; make it easy to transport individuals from place to place and you provide a means of making people contented, happy and progressive, and you advance civilization.

Conditions have come about that make it extraordinarily difficult for electric railways to transport individuals from place to place. If these conditions were to become permanent, there could be no question about the resultant demoralization of human existence. "Man cannot live by himself alone," has a practical business application as well as a spiritual one, and when conditions are allowed to remain that tend to isolate him from his fellow creatures, he slips toward decadence.

The reasons for the present day condition of the electric railways are many, and vary according to local conditions on the different properties, but there is one fundamental cause—the unwillingness of the public to consider the problems of the railways in the same reasonable manner in which the individual considers his own affairs. This unwillingness to act is not due to any inherent unfairness in human nature, but instead is due largely to the public's lack of understanding of public service corporation problems. In the past there were financial operations that made the people skeptical as to the honesty of purpose of some public utility operators. The demagog long has been abroad in the land, and the demagog has used the sins of some few operators of bygone days as a text for the condemnation of practically everybody engaged in public service. Certain persons have found profit and personal advancement by attacks on the utilities, and their utterances have found ready applause and belief. The utilities in the past earned dividends, and if they do not earn dividends today, well, "good enough for them," say the people who have been told that they were mulcted in the past. The demagogic politician has access to the public prints and has the ear of the plain people because he wears the heroic garb of one seeking to save the innocent from ruthless exploitation, while the plain, truthful, matter of fact statements of those serving the people with the utilities have often been regarded with suspicion and distrust.

Reiteration of truth must in time convince the people that those who would serve them best are not the self-seeking demagogs who shout so loudly from the housetops. The American people are inherently fair minded, but must "be shown." It is the duty of the utilities to show them that conditions, among the electric railways, at least, are such that if relief does not come soon this great industry will be so seriously crippled that great public suffering will follow. The people are, I believe, gradually coming to the realization that the electric railway problem is a great civic and community problem, which must be considered in

all fairness. Blind prejudice must give way before the light of truth. Ignorant and malicious opposition must fall before intelligent and frank presentation of fact.

Meanwhile the utilities cannot sit idly by and "hope for the best." They must be up and about, spreading the truth where all can find it. To bemoan misfortune never won relief for anyone, and too persistent mourning destroys rather than creates sympathy. The day of mourning in this industry is passed. The time of reconstruction is at hand. Let us state our condition and our problem to the public in terms that the people cannot misunderstand; let us show them that our cost of living has gone up in proportion to their own; let us show them that we ask nothing to which we are not entitled and which they, as fair men and women, are not willing we should receive. The means by which we shall win public co-operation may be various, but whatever they be, their foundation must be frankness, truth, common sense and a genuine desire to serve.

City Traction Problems

A. W. THOMPSON
President,
The Philadelphia Company, Pittsburgh

ELECTRIC traction lines in this country are going through their darkest hour. The process of solving their difficulties has already begun, and this in itself is worth much to the industry. It is inconceivable that an effort conscientiously undertaken and earnestly carried on will not bear fruit. Public opinion and attention is being engaged from which a real sentiment can grow.

A public service company exists only to serve the public and can exist only when it serves the public. Rendering a public service requires an adequate property to give adequate service and a continuous adequate return to furnish that service and insure its continuance. The basic conception in the development of a public service is the public, a sufficient population existing or likely to exist in the near future to justify the construction of the utility. This justification must be the assured prospect of the utility, supporting and paying for its operation at once or in the very early future. The whole being of a public service begins with the public and its continuance at all times is based on the public.

An analysis of the public develops several distinct categories; the investor, the management, the employes to produce the service, the people of the community or communities as a whole, collectively, with their residences, offices, stores, shops, factories, mills, theatres, amusement places, parks, etc., producing the need for the service, and the patron or customer—the rider in the case of an electric railway—for whom the service is produced.

The point to be kept in mind is that while an electric railway enters directly into the every day life of a majority of the residents of a community, it also enters as directly into almost every activity conducted in the community. This intimacy of street car riding with our modern city life is sharply brought home to all at the time of a traction strike.

The commutual aspect was early recognized by local legislative bodies in their franchise enactments and in imposing various obligations on the street railways, such as street paving requirements, street cleaning assessments, park taxes, etc., and was further recognized in the state public service bodies. The public through its duly authorized representatives bestowed on the traction companies more or less circumscribed monopolies, and it was deemed proper to secure something in return for the franchise.

In the days of horse cars, the animals wore ruts in the paving and littered the streets, so that paving and street cleaning assessment, if properly imposed, could not be considered unreasonable. Then, too, it was supposed, with the convenient transit for those days, that people would flock to the public parks, and that the railways should bear a part of their upkeep; hence the park tax.

With the development of the electric car from the horse car, and latterly the development of the automobile, conditions have considerably changed. The electric car neither wears ruts in the pavements nor litters the streets. The advent of the automobile has considerably increased the expense of amply maintaining the parks. Yet the car rider still has to pay for these things when the modern service provided for him has no relation to them whatever.

When, with too many electric railways it is not a question of returns on the property investment but the absolutely vital ones of operating expenses and sufficient maintenance, it would seem that the whole field of the relations of railways with the public should be opened for discussion and carefully studied, for it cannot be denied that the usual life of many communities would be seriously embarrassed, if not stopped, were their street railways to give poorer or lessened service or to cease operations permanently.

Lasting improvement in traction affairs calls for all parties to approach the problem with open minds, and for a determination to be fair, with an appreciation both of what the communities have done for their railways and the railways for the communities, the absolute necessity of each for the other and their positive mutual interdependence; that each may effect and enjoy the confidence of the other.

Unfortunately, we have not yet reached that millenial time when an individual or a body of individuals will work for the benefit of others without remuneration. It is incumbent that neither the community, the worker nor the property be starved, that the railways work under fair contracts with their communities—contracts that will insure adequate returns on the moneys invested, provide incentives for improving the service and reward the companies for reducing the fares.

The necessity for efficiency and adequate traction

service in every city is so great that it is inconceivable that this important phase of our social life will not receive sufficient attention in the near future to protect the public properly in all of its phases. At the present time, many are not taking the interest in this public problem that they ordinarily would because of the thought that the importance of the subject will demand such attention as will place the traction lines on a proper basis. The attitude of Public Service Commissions as a whole is such as to warrant the feeling on the part of all financially and otherwise interested in traction companies, that with the splendid help of the Commission the problems will undoubtedly be worked out much earlier than would otherwise be the case. It is also true that municipalities are studying this traction problem with a view of arriving at an early solution. The various traction properties that are now undergoing the process of valuation, or on which valuation has been determined, are fortunate in that the bugaboo of watered stock, etc., has been or will be eliminated.

It is said in some communities that "jitney" or omnibus service will substitute the traction lines. Except for short-haul distances and for some shuttle service, the idea of omnibus lines supplanting the traction lines surely is not to be given very serious consideration, keeping in mind, of course, the cost of service. With a better understanding of these matters by the public, which in the past has not been possible, either through lack of proper methods on the part of the traction companies or indifference on the part of the public, these traction problems will be greatly simplified.

Co-operation between the traction companies, the municipalities and communities, with sympathy and understanding between them all, will only work out to advantage to all concerned these transit problems so vital to the social structure of society and urban life. The intelligent working out of these problems will tend to produce greater incentive for cheapening the cost of operation through various methods of operation and maintenance. The whole field of the traction activities looks encouraging.

Inherent Defects and Future Sphere of Usefulness of Electric Traction

EDWIN GRUHL
Assistant to President,
The North American Company

PUBLIC opinion of the street railway problem is entering a new phase. Public apathy, faultfinding, indignation and finally alarm are being succeeded by an aroused public conviction of the necessity of street railway transportation. New York, Chicago and scores of other cities have passed through a temporary paralysis that has cost the community more in one day than it has paid for such service during the entire year. Underpaid labor, ruined credit and a frayed political issue have forced the crisis. Hints of labor troubles, announcement of receiverships and the usual political interviews were third page stuff. Even front page headlines were not necessary when the works shut down. Public opinion, so busy with other weighty problems, has hitherto given the street railway problem little thought. It has admired the literary effort of educational publicity; it has wondered at the occasional row of public officials and traction officials in the news; it has grumbled at the service, just as it grumbles at the many petty inconveniences that mar the harmony of daily life. But public opinion aroused will not tolerate conditions that threaten a cessation of transportation service. The problem must be settled. It may mean higher fares. It may mean public subsidy. It may mean public ownership. The opinion is unanimous that present conditions cannot continue.

The situation in which the street railways find themselves has not been brought on by the war. It is not an incident of reconstruction. It has been a gradual development. The growth of cities has resulted in longer hauls. The increase in standards of living has resulted in suburban development and the demand for non-paying extensions and more rapid transit. Community habits have resulted in increased demands for service during the morning and evening rush hours. Year after year the load has become more peaky and the facilities given less constant use. With fixed fares the business was certain to be one of diminishing returns. These tendencies have been commented upon by students of the traction problem years before the war. The war has merely accelerated the process. Diversity of business hours and timely restrictions on the height of buildings might have relieved the pressure and retarded the congestion. Zone systems of fares might have resulted in some closer relation of revenues collected and cost of service. The downward tendency however has continued unchecked.

In addition to these inevitable tendencies, the era of high prices has brought further difficulties. The decrease in the purchasing power of the nickel has necessitated a proportionate increase in rates of fare for the same service. Unfortunately higher prices for an identical product result in reduced patronage. The great burst of free spending is for higher grade commodities. The public will cheerfully pay three times as much for a rubber-tired-ride but will begrudge an additional few cents for a street care fare. The average American very readily adjusts his standard of living to choice cuts, mineral waters and silk hose, if he has the means to do so. A reaction from this tendency may be expected when rising prices reach their new permanent level and all commodities are uniformly revalued on the basis of purchasing power.

It does not follow, because of longer hauls, poorer load factor and decreased patronage, that the traction business has no economic justification for continuing in business. The gain from transportation service has been a social one reflected in the increment in realty values. No other single factor has contributed so greatly to city growth as local transportation service. Nor is it at all probable that the street

railway will be superseded by other forms of transportation service such as the automobile. Economy of space, of labor and of motive power all contribute to make the electric railway the cheapest form of transportation service.

The problem now pressing for solution, then, is not fundamentally one of improved public relations or rehabilitated credit or financial reorganization or franchises. These are incidental. The problem is one of city planning—a mutual problem for both public officials and traction companies. To be as essential to city growth and prosperity in the future as it has been in the past, we must reconstruct many of our ideas as to the function of a street railway. Electric package express, freight, the haulage of ashes, garbage and building materials would relieve congestion, minimize wear on paving and provide the most economical form of intracity distribution. It would provide the maximum use of existing facilities. Properly co-ordinated by schedule—freight being moved in non peak hours—it would result in the maximum traffic development. It would materially expand the areas devoted to industry. It could be supplemented by pick-up and delivery truck service and by additional motor service at outskirts where traffic density does not justify the laying of rails. Such a plan assumes the co-ordination of real estate zoning plans and traffic plans and a definite city policy for community growth. It assumes moreover a definite program of regulation of vehicular traffic in the interest of rapid movement and elimination of congestion.

With such an enlarged sphere of usefulness, the economic aspects of the business would be materially changed. Tariffs and charges could be designed to promote the maximum traffic and the necessity of public subsidy, either under private or public ownership would be minimized.

The Future Outlook for Large Urban Electric Railways

F. G. BUFFE
General Manager,
The Kansas City Railways Company

It does not signify much to say that the future outlook for city properties is better. After the depressing period through which we have passed, it does not seem possible for the future to offer anything worse. There is no reason to believe we are in the fix of the gambler who had been having a run of hard luck and went to the fortune teller to get some inside information on the future. She told him that his luck had been very, very bad, but it would change, it was going to get worse. So, if we are willing to say that the future outlook is better we might as well go a little further and say that it is fine; that for the first time in three years things are beginning to look as if there was some sunshine back of the clouds. Many straws point this way. The consulting physicians who have been attending our death bed scenes for three years, at last seem to have finished their consultation and decided that our life must be saved.

Here is a foundation principle upon which to base the future outlook. Street railway transportation is absolutely essential to the well being and existence of our cities. There is nothing today or in the immediate future to supplant it; therefore, being necessary and essential it will be continued and to be continued must be suported.

First and foremost, the street railways of the country are at last co-operating and the results are now becoming apparent. The presentation of the case before the President's commission by the committee of one hundred supported by the magnificent work of the American Electric Railway Association is bearing fruit. From this commission doubtless will come a report and recommendations that municipalities cannot pass by unheeded.

Second, the public is becoming aroused to the danger of the complete disruption of its urban transportation service and is awakened to the necessity for taking immediate action to insure its preservation.

Third, the experience of government operated railroads has done more to put a stop to municipal ownership talk than all the publicity of the past ten years. A number of places have voted on the purchase of their street railway by the city and turned the proposition down. This has cleared the atmosphere and leaves without much competition the only real solution of the present street railway system, which is service at cost.

Fourth, the status of the street railway problem is no longer a number of local situations. It is a national emergency and today there is more united co-operative effort to work out some solution than there has ever been. An example of this is the action taken in Kansas City, where the chamber of commerce has appointed a committee of one hundred of its biggest business men to make a thorough investigation and report some solution for the street railway situation. These men have given their time day and night in the hottest months of the year to this work. They have out of their own pockets raised a fund to pay the expenses of their committee. It is an encouraging and hopeful sign. When these men have finished, the street railway situation in Kansas City will be placed before the public authenticated by this committee and the public will have unbiased facts upon which it can rely.

Fifth, the labor situation has, up to this time, been one of the stumbling blocks to a permanent solution. Settlement after settlement has been reached in many cities and then the demands of the car operators have put the entire question back to where it started. It has seemed that there was no limit upon which to base conclusions. The "Cost of Service Plan" makes wage increases payable by the public not by the company. This being the case, an enraged public sentiment will not tolerate unreasonable demands for wages or hours. If it means a strike, that strike will not have the support of the public and without public opinion no strike can be won.

Sixth, increased fares. There is some encouragement in the hope that we have passed through the psychological effect of fare increases; in other words, the public generally has ceased to look upon a street railway fare as five cents. With this advance, the public will sooner or later adjust itself to fares based on the cost of service, as it has to other price increases.

Seventh, the increased cost of automobile operation and the difficulty of parking cars down town may have some effect in reducing the use of private automobiles. Good service will help this. Municipalities generally are coming to realize that jitney competition is unfair and means penalizing the great majority of the people who must depend on the street railway company for the few who avail themselves of the itinerant jitney.

Eighth, the wide spread use of the safety car is a big factor in solving the problem. Its adoption, with accompanying decreased headways, means more travel; it means an increase in net revenues, in some cases running as high as two thousand dollars per car per year. The safety car is no longer an experiment and it can be stated from actual experience that, on any line which does not have a headway of less than four minutes, it can successfully be operated under any traffic conditions. To a large extent its use solves wage problems as the economies it makes possible will permit the payment of a more than reasonable and satisfactory wage.

There is no real reason today for being pessimistic over the situation. All things are working together for our good and already there is a brighter future outlook for the street railways. They are absolutely essential; what is essential must be continued and what must continue must be supported. The price of service must meet its cost and, for the first time since the inception of the industry, it is going to be put upon a strict business basis where its product will be sold for what it costs, plus a fair and reasonable return to those who have invested their money to make possible a necessary and essential public service.

Hold Fast to the Fundamentals

F. W. HILD
General Manager,
The Denver Tramway Company

IF THERE is one thing that has come out of the experiences of the past few years it is the lifting of the essential things of our daily life into public view and appreciation, out of the rut of commonplace, out of the dust of indifference where they had been consigned by a careless public which had gotten into the habit of looking only for the new, the strange, the startling things which each day brought forth. When we began to take an active part in the great war drama, we suddenly awoke to the fact that enemy activities might imperil the water supplies of our great cities and this very essential but commonplace commodity at once assumed an importance in the public eye which only the placing of armed guards for its protection could bring about. Coal, the humble mineral so carelessly and wastefully handled everywhere, suddenly leaped into dominating importance with the public recognition of its essential character as a fuel; likewise with many of the humbler items constituting our food supply.

Rather more recently has it been borne home into the public consciousness that organized urban transportation, as represented by the electric street railways, is an essential public service. It is true that it required actual or threatened cessation of the supply of these various necessities to bring about the public appreciation of their indispensable and important nature, but at least it has been accomplished, and so in the discussion of the electric railway situation we have passed the period where it is necessary to convince our fellow citizens that organized urban transportation is an essential institution in our modern life.

In the minds of many of our people the belief had taken hold that the last days of the street railways were in sight. Some men prominent in municipal affairs even went so far as to say that it mattered little what happened to the street railways, since other means of transportation, such as that by rubber tired gasoline vehicles, were at hand to take its place. That these men had not studied the situation or were sadly misinformed is now a demonstrated fact. It needs but little argument to convince the few who still cling lingeringly to the former fallacy, that a steel wheel on a steel rail offers the minimum of frictional and rolling resistance, many times less than that between the rubber tired wheel and the rough uneven surface of the ordinary street or road. It is quite generally appreciated that the cost of moving a passenger one mile by rubber tired gasoline transportation is from six to nine times that of moving a passenger one mile by electric railway, even under present conditions; and if the burden of street paving and road costs be added to the rubber tired transportation in like proportion to that now carried by the electric railways, the advantage in favor of the latter in point of cost will, of course, be much greater. Thus taking a typical rush hour load and using the item of fuel alone as the principal element of power expense, the fuel cost per passenger per mile for the street car is around 0.0143c, with coal at $3.50 per ton, while at the same time the fuel cost per passenger per mile for the average passenger automobile would be around 0.36c with gasoline at 26c per gallon, showing that the fuel cost is twenty-five times as great for the automobile passenger as for the street car passenger. All this is of importance in any real and sincere consideration of the H. C. L. problem.

Of perhaps equal importance, though doubtless less well appreciated at this time, is the much greater economy of street space of the electric railway in urban transportation as compared with rubber tired gasoline transportation. As our cities continue to congest through the erection of tall buildings in their business, commercial and industrial centers, thus concentrating vast numbers of population in limited city area, this will become increasingly emphasized. Thus, for ex-

ample, in Denver an electric motor car with its trailer seating 100 passengers and capable of carrying 80 standing up, or a total of 180 passengers, occupies 100 feet of lineal street space while passenger automobiles to accommodate the same number would require 520 feet of lineal street space. So today it is quite well established that the electric street railway is the most economical form of urban transportation in point of cost and of street space occupied.

For all these reasons the electric street railway is bound to live and if, here and there, or now and then, it is denied or delayed its right to earn or receive all of the revenues necessary to its continued operation and existence, such delay is at worst but temporary, and must sooner or later yield to the inexorable working of economic law. It is the bounden duty of those charged with the trusteeship of the various properties to avoid pessimism as to the future of the industry and, not to weakly surrender to the troubles and difficulties of the moment, no matter how large or ominous they loom. With that grit and determination that have always characterized the American business man, each should tackle his particular traction situation and work out the solution as he would any other hard, complicated, difficult business problem. It can be done and it will be done.

Many mistakes have been made at various times in the history of electric traction but, in this respect, the industry is by no means unique, as the same experience is true of every other business and of men in all other businesses. The important thing now is to recognize the changing conditions and readjust policies and methods accordingly.

Public utilities, and particularly electric railways, long ago left the field of unregulated, unrestricted business endeavor. Regulation in some form or other—municipal, state or federal—is now a universal concomitant of the utility business, and regulation in whatever form must finally be based upon value. Therefore the wise, foresighted public utility operator will at the earliest, most favorable and apropriate time cause the fair value of his property to be established officially. When that has been done satisfactorily the enterprise will be on a foundation which, with reasonably intelligent management, should enable it to weather practically any storm that may come. Thereafter local conditions and circumstances will largely govern the working out of the rest of the problem, whether it be ordinary regulated operation, the service-at-cost plan, partnership arrangement with the city, or municipal ownership.

Others will tell of economies and reductions in operating cost to be effected here and there through one-man cars, through new methods of power supply or distribution, such as the automatic substation, through improved maintenance methods: also others will tell of various ways and means to augment the revenues by new ways of securing freight business, by this or that system of passenger fare charges and collections. Yet in times of stress and storm one is apt to lose sight of the fundamentals and be carried away by symptoms or by passing difficulties and temporary trying experiences. Hold fast to the fundamentals, the electric railway is an essential industry. It must and will live.

Utility Credit and General Prosperity*

THEODORE P. SHONTS
President,
Interborough Rapid Transit Co.

HOMER L. FERGUSON, president of the United States Chamber of Commerce, testified before the Federal Electric Railway Commission in Washington that he regarded the condition of the electric railways as the most acute business and financial problem in the country today. He is not an electric railway man, nor a banker. He is a shipbuilder. As president of the United States Chamber of Commerce he represents all manner of industry. Such testimony demands attention.

Too much stress cannot be laid upon the importance of maintaining the credit of the electric railways as a vital part of the nerve structure of the nation's business. To maintain their credit, the authorities must maintain the parity of the car fare. It has depreciated fully 50 percent. The nickel is worth only half its former value, but the street car ticket is worth as much as it ever was. A 10 cent fare would be no higher in purchasing power over things needed to provide service than the 5 cent fare used to be. By the same token, the 5 cent fare is a much smaller portion of the people's wages today than it used to be.

To assure the credit of utilities, the laws of most of the States specifically declare that investors in public utilities are entitled to a "fair return" upon the "fair value of their property." The constituted authorities have no legal formula for determining a "fair return", but they are supposed to take into consideration the risk involved in the investment. Their powers, in fact, are so great that the attitude of the commissions or city bodies is one of the most important of the risks considered by investment bankers and private investors. A decision affects not only the credit of the company at bar, but all companies in its class. A hostile attitude toward the utilities raises the rates at which capital can be borrowed for their use."

Few of the general public realize the magnitude of electric railway investment. The securities of the electric railways (subways, surface and elevated) in New York City alone aggregate about $272 000 000 stocks and $735 500 000 bonds. Those of the rest of the State are about $124 000 000 stocks and $152 000 000 bonds. The total is more than a billion and a quarter of dollars. In the United States it is more than six billion dollars. This vast sum of utility securities is in jeopardy, and it is in jeopardy because, notwithstanding the request of the President of the United States, the Secretary of the Treasury, the Comptroller of the Currency, the War Labor Board

*Revised from his communications to civic organizations of New York City

and the plain facts, the local authorities in many places have not permitted the companies to increase their fares sufficiently to meet abnormal costs and to protect their credit in conditions they are in nowise responsible for. Some are already bankrupt; all are headed toward the rocks.

In such conditions banks cannot but refuse loans on such securities, thus seriously restricting credit; and they cannot invest or advise investment in such enterprises. Even in normal times default on securities on any such scale, or even a large part of them, would be an absolute disaster, so far do the nerve threads of the credit structure ramify. But times are not normal. Following the most gigantic war in history is a period of reconstruction on such a huge scale as to make the credit of many of the nations questionable and credit, even in our own country, extremely sensitive.

Again, the loss of capital through bankruptcy is just as serious as loss of capital through war. The basis of taxation is the wealth of the citizens. If any large proportion of this invested wealth were to be eliminated from the taxable wealth of the States the burden left for the remainder would be staggering. To assume seriously that the credit of these vast and essential organizations can be put in jeopardy and the effects localized or even restricted to utilities is at least highly dangerous. Every city's general business credit is sympathetic to the credit of its utilities. Cities cannot be prosperous without efficient utilities; and utilities cannot be efficient without prosperity.

Public regulation of rates involves public protection of credit. What economic law does for ordinary business must be done for the utilities by the bodies having their existence literally in their hands. Investors cannot be coerced; they must be attracted. Utility investments, therefore, must be attractive in competition with other investments. They should be even more attractive, for on them public convenience depends. But in utilities profits are limited. "Excess profits" are not allowed in fat years to provide against the lean. And this doubles the duty of protecting them in years of adversity. Good credit is vital to a utility's possibility for good service. It is a cornerstone in the whole modern business structure. Start the bricks falling, and there is no telling where it will end.

Public Utilities—A Diagnosis

THOS. S. WHEELWRIGHT
President,
Virginia Railway & Power Co.

When the electric trolley and electric light came into being thirty years, or a generation, ago, the new enterprise was viewed with suspicion and condescending incredulity by the well-entrenched and established financial interests which had developed and profited by the horse-car and gas interests. They were skeptical as to the practicability of the new system and used all of their power, both financial and political, to make the way for the trolley and electric light industry difficult, hence the projectors of the new enterprise felt obliged to "fight the devil with fire" politically and had to get their first opportunity for trial under "horse-car" franchises with all of the conditions as to paving of streets, taxes on gross earnings, and other erroneous conditions which were imposed through political influence. In short, they were able to obtain only temporary permits with many restrictions in order to test out the electric trolley on the new routes covered by the "horse-car" franchises.

The electric trolley and the electric light system accompanying it had their birth, therefore, in a highly-charged political atmosphere and were promoted by men who were regarded by the conservative interests as interlopers and experimenters in finance. They, nevertheless, did a great and important part with costly capital and against political odds in developing through the "trial and failure method" what has now become a most vital factor in community life.

After the final practical demonstration of the success of the electric trolley in Richmond, about 1889, similar enterprises were promoted and established throughout the country, the promoters accepting whatever franchise terms were obtainable and by whatever method they could be secured, often consolidating with the old horse-car and cable lines, thus inheriting not only the burdens of the obsolete system, but the franchise provisions and restrictions as well, such as street paving which, for the horse-car line, was a proper indemnity for the damage it did to the streets, but which when applied to the electric trolley became an additional tax for the franchise.

Probably the most serious economic error in these first public utility franchises was committed in fixing the date of death at the time of its birth by limiting the life of the franchise to 10, 20 or 30 years, rendering it necessary, in order to attract the needed capital, to adopt a highly speculative financial plan by giving stock bonuses with the bonds in order to induce investment, and making no provision for amortization of the capital invested by the date of the expiration of the franchises.

The next serious economic blunder was the acceptance of a fixed fare of five cents, regardless of the length of the ride and the issuance of free transfers between the several lines in a community, thus deliberately contracting to "sell short" for a long period a commodity the cost of producing which it was impossible to calculate with any degree of certainty.

Hence, now that this first generation of public utilities is now approaching its predetermined date of demise, having been through innumerable receiverships, having not amortized the investment of the original capital, nor made adequate provision for repayment of the ever-increasing capital expenditures for improvements and extensions, the utilities find themselves in a very bad plight and quite at the mercy of political influences. They are thus obliged to give heed to the various superficial remedies prescribed by those who have their own political future to consider, regardless

of the proper consideration for the capital and enterprise which has been by far the largest factor in creating the great increase in urban and suburban values upon which the entire structure of community life is built.

Until the recent national demonstration of the costly and inefficient operation by the Government of railroads and utilities, and also the recent development of similar experiences by municipalities, municipal ownership has been heralded as the remedy on the basis of taking over the properties on a replacement valuation. This theory, however, is now being conceded as manifestly unjust, as it results in the confiscation of capital invested in the development of the enterprise as a "going concern" and makes no just recognition of the fact that the utilities through their constant service through these many years have created great enhancement in values of all other property and are entitled to the same proportionate recognition of enhancement in values with due regard for the continuous capital expenditures which have been necessary in keeping pace with the development of the community. By reason of the heavily increased costs of operating on the one hand, and the "short sale" compensation fixed in the original grants, on the other, and the additional restrictions and obligations constantly being imposed, it is imperative, in the interest of the community they serve, that a fundamental remedy be found quickly and applied to save the utilities.

Moderation Must Govern Future Municipal Action

A. M. LYNN
President,
West Penn Railways Co., Pittsburgh

NEARLY every kind of obligation that the authorities in power have been able to devise has been imposed in different localities upon the street railway utilities in connection with the use of the streets and public highways—running the gamut from furnishing free transportation to public servants, to actually surrendering a considerable part of the operating revenue. While it is not the intention to enumerate here all of the burdens that have been imposed, one of the most conspicuous causes of loss and embarrassment to street railways has been the thrusting upon them of the expense of certain paving, not only originally but also of every change in grade or other improvement, whether advisable or experimental, besides compelling facilities to be provided for the general public, as in the building and maintenance of bridges, for example, which augment the cost to the railways without any resulting counter benefits. Moreover, such conditions are often further aggravated by the uncertainty of action of the municipal government, or its various branches, in the matter of street betterments (and correspondingly the expense the trolley company must bear) so that the management is thus distracted from time to time from the pressing duties of operation. Due to the increasing use of the automobile truck, and other heavy traffic, municipalities are finding it necessary to adopt more expensive forms of street construction, resulting in further additions to the already soaring cost of street railway operation.

The obligation of paving was first imposed upon street railways when they were operated with horse cars. At that time it was not customary for streets to be paved in the smaller cities, and it was considered a fair obligation to impose upon street railway companies the burden of maintaining the street between its rails. Since the adoption of electrically-propelled cars, the street railways do not add to the depreciation of the street, and therefore, should not be obliged to maintain the paving except when, for their convenience, they disturb the existing pavement.

Extensions of lines into sparsely settled districts, which gave no promise of proving profitable, have been forced upon different companies. Where Commissions have jurisdiction, the companies may now escape some of these hardships but in the past different communities have often accomplished their purpose by the threat of or actual resort to unwise competition, many cases of which are now reflected in the present street railway situation. Although shifts in traffic have naturally occurred in some sections of the community, service under ordinance stipulation is still enforced under duress of forfeiture of the rights of the company to occupy such streets.

Maintenance of unreasonable schedules has operated to reduce the earning capacity of otherwise favorable lines. Inordinate extension of the fare limits as the corporate lines or suburban districts were pushed out beyond the original areas has been a real source of waste in the conduct of the business. In business, anything that is or must be carried on continually at a sacrifice cannot result in any permanent good, unless there are some indirect benefits accruing, which justify the practice.

Excessive assessments, either in the way of taxes, rentals or division of gross revenue, mean nothing more than the shifting of the responsibility of the burden from the citizens as a body to that of the car riders. There is evidently a limit as to how far any such unfair distribution of municipal expense may be carried, for the economic law underlying this commodity or service will be felt, as in everything else, and it hardly need be emphasized that we have already plainly seen "the handwriting on the wall". Any further exactions will hasten the complete collapse of local railway transportation, which would obviously redound to the serious disadvantage of the communities affected. One need only turn to the estimates, often published, covering business losses sustained in connection with a complete tie-up of a street railway by reason of a strike. The injury which a railway suffers from the financial drains above mentioned works harm to the community in like manner but to a lesser degree than that forcefully

demonstrated in the short period in which service is suspended by a walkout of its employes. However, it is continuous in its process and, therefore, in course of time becomes far more serious.

This situation cannot be corrected by repeated advances in fares, on account of the economic reasons already mentioned. As the fares are increased, traffic is diverted and the point is soon reached where the direct loss overcomes the apparent gain.

The cost-of-service plan, whereby rates are automatically regulated by the variation in the level of funds in a surplus reservoir, is frequently referred to as the panacea for the ills of local transportation. Where the city assumes direction of the extent and nature of the service to be rendered, and where schedules are inaugurated without regard to any real economic or social needs, the only merit in such a solution is that it provides some safeguard for the capital invested. On the other hand, there can be no substitute for the old order wherein business was actuated by the incentive of an appropriate reward for competent management. A complete restoration of that policy, along with supervisory state regulation (without destructive municipal interference), would certainly promote progress.

There should be a uniform franchise which does not contain burdensome obligations in the way of license fees, or taxes for cars, poles, wires, street sweeping, sprinkling, etc., or on any of the facilities necessary to the operation of a street railway. A street railway is a large contributor to the growth and prosperity of the community, and to afford the best service, its revenues should not be diverted to help pay the expenses of municipal operation.

At their incipiency, the street railways might have been subsidized in the manner that many governments foster their infant industries, but this period is past, and it is not to be expected that the street railways will require any direct financial aid, unless it be in the way of utilizing municipal credit. They must, however, have relief from undue strains under existing ordinance requirements.

The time has not arrived when we may feel warranted in losing our faith in the public at large. In spite of the persistent opposition heretofore encountered, let us confidently hope that a rational and real American course of treatment will presently be meted out by the municipalities, when the railways will be compelled to perform only such duties as are inherently a part of good service.

Service at Cost

CALVERT TOWNLEY
Assistant to President,
Westinghouse Electric & Mfg. Co.

SHAKESPEARE said "What's in a name?" but slogans have been valuable adjuncts to success almost since time began. Just now the slogan "Service at Cost" seems to have caught the fancy both of the public and of the trolley companies and various plans under that caption are having their day in court. Perhaps the one which has attracted as much attention as any is that forming the basis of a contract between the Boston Elevated Railway Company and the Commonwealth of Massachusetts. This plan provides in effect that the rate of fare shall be automatically changed from time to time and shall cover cost of service only. Cost is defined as including the ordinary operating and maintenance expenses and also a fixed return on the capital invested. If the revenues of the corporation shall at any time fall below this cost, the difference is to be made up by the State.

This plan reads well. To the uninitiated, it appears to offer a very satisfactory solution of past troubles because no one who rides should object to reimbursing the carrier for the cost of his transportation and, if the owners of the property are willing to forego all profit, it is obviously only fair that they should be relieved from the hazard of loss.

How has the plan worked? The Boston Elevated Railway Company, under corporate management, had a five cent fare and although they complained that it must be increased on account of the increased cost of service, they were not given much encouragement. Since the management of the property has been taken over by a board of trustees appointed by the Governor, the fare has been raised by successive stages until it is now ten cents and I am informed that the road is still operating at a deficit. Dissatisfaction has been widespread and a bill has been passed by the Massachusetts Legislature establishing five cents as the standard rate of fare on all trolley lines within the State and providing that wherever this fare may not be sufficient, deficits are to be paid from the public purse and funds therefor provided by an increase in taxes.

An article published in the Boston News Bureau some months since, when the fare was seven cents instead of ten and before the present wage scale for employees had been reached, gave figures to show that Massachusetts was in a fair way to have to double its maximum pre-war tax levy to provide for the probable deficit which would result from the Boston railway venture. The article pointed out how this fact might startle the taxpayers; for example, those in Springfield. Pittsfield and communities in other parts of the State who do not use the Boston utility but who would share the tax burden. With the rates of wages now prevailing and if the State would arbitrarily return to a five cent fare, this situation will become just that much worse.

This object lesson would seem to make it reasonably clear that the much talked of solution of the Boston transit problem was in fact no solution at all but a gigantic mistake. The reason seems fairly obvious. What the people wanted and thought they were getting was "Service at a Low Price". They

could not believe that there was no profit to the railway company in the prevailing rate and they accepted the slogan "Service at Cost" thinking to save the profit which the Company had been making.

In making this contract the State authorities seemed contentedly ignorant of the fact that cost without profit to anyone may be considerably higher than a price which includes a profit to somebody who has an opportunity to share it. That is to say, they completely lost sight of the fundamental fact that costs can be kept low only by a combination of ability, authority and incentive. While they could perhaps employ able men, their authority would be weakened by politics and an incentive would be absolutely lacking. It is another plain case of government operation and consequently another failure. Wherever you now find a man who still favors government operation, you may be sure he has an axe to grind and may be described by the old saying—"There are none so blind as those who won't see".

It should not be necessary in this day and generation to point out again that the production and sale of transportation is fundamentally like every other commercial undertaking, and subject to the same economic laws, or that no great constructive effort has ever been initiated and sustained except by private enterprise, or further that the removal of the incentive of private gain invariably kills initiative.

These facts ought to be accepted as axioms by this time. The Boston "Service at Cost" plan ignores them all. "Cost" has gone up because nobody in the organization gains by keeping it down. The present invested capital is made safe and new capital may doubtless be procurable for additions and betterments but whose capital will it be? Obviously it will come from the timid or from the man who has enough already and is concerned only to keep it. Progressive constructive investment comes only where vigor and brains have a chance for gain and are therefore willing to take a corresponding risk of loss.

The Federal Commission at Washington is collecting facts and opinions galore and presumably will later submit a report with findings and recommendations regarding the general trolley situation. It is to be hoped that whatever plans they may propose, they will at least recognize the fact that, as practiced, the regulation of utilities has failed and also that "Service at Cost" has been and must continue to be an expensive and unsuccessful experiment. If the street railway industry is to be restored to a condition which will permit it adequately to perform its public functions, as an essential adjunct to present day progress, it must be freed from all unnecessary shackles; the corporations must be equipped with as much authority as are the corporations operating in other industries and they must be permitted a real incentive. If this be done, no one doubts but that they can procure ability to produce successful results.

The Graduated Fare System

N. W. STORER
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THE STREET RAILWAY Companies of the United States are just now facing the darkest days of their history. While in the last year there has been a considerable increase in fares all over the country, it is generally conceded that this has not increased the gross receipts sufficiently to save the companies from bankruptcy.

It is quite natural, at a time when prices of everything else are rising steadily, that the street railway managers should look to increased rates of fares to solve their problems, but unfortunately the problem is complicated by other factors than simply the rate of fare, and this solution has the effect of killing the goose which lays the golden egg. It is therefore plain that the problem must be studied from the broadest viewpoint before it can be solved. Even before the war boosted prices to such an abnormal degree, the affairs of many street railway companies were approaching a crisis. The effort to furnish the high-class service demanded by the public had brought forth the heavy double-truck cars which were expensive to operate not only on account of their great weight per passenger, which increased the power consumption, but from increased maintenance both of cars and road-beds. The great expense resulting from obsolescence piled up huge debts on which interest must be paid. The increasing lengths of lines and the transfer system increased the average cost of hauling passengers.

The development of the automobile and the tremendous growth of that business introduced an entirely unexpected competition for the street railway companies. Where they once had a monopoly they have suffered a heavy loss of business from the privately owned automobile, and are now obliged to compete for traffic with the jitney and the motor bus. This competition reduced the patronage in many places to such an extent that the service had to be decreased, which resulted in a further loss of business. Then came war with its pyramiding costs to complete the ruin of the companies.

The best minds of the industry are now working on the problem of how to save the companies and preserve the industry which has played such a vital part in the development of our cities. Many solutions have been offered, but the ones which appear to have the most promise are the following:—

It goes without saying that a higher class of service must be given than has been possible in the last few years. This means more frequent and reliable service, along with clean cars, courteous treatment by employees, etc.; in other words, the service must be made so attractive that people will ride on the street cars because they want to rather than because they have to. On many roads the introduction of the light safety cars with the more frequent service has demonstrated that

this plan alone will effect a great increase in the traffic, while at the same time reducing the cost of operation.

"Service at Cost" is also looked upon in some quarters as being the solution. Municipal ownership has its supporters. But neither service at cost nor municipal ownership can be satisfactory or successful in the highest degree without a more equitable distribution of the cost of operation.

The graduated fare or zone system offers to date the only feasible plan of securing this. Such a system is just as desirable for the street railways as the meter system is for electric light companies. No large electric light company would undertake to operate at this time on the flat rate system, which was the plan under which electric lighting was originally introduced. The price of such service would be so high that no one would buy it, and the business would be at a standstill or go into bankruptcy. This is exactly the situation in which the street railway companies of to-day find themselves. The mere fact that the street railway business has been built up around the flat rate system is no argument for its continuance at this time. The increase in fares which have been made all over the country have shown clearly that the amount of patronage is dependent very largely on the cost of riding, as every increase in fare is followed by a decrease in the number of passengers, showing that those who can reach their destinations in other ways are doing so, and many who cannot do so are staying at home. The street railway companies are thus driving away the customers from whom they derive the greatest profit; they are reducing the number of people from whom they can derive revenue, and to this extent they are failing in their duty to the cities which give them their right to occupy the streets. It is entirely unreasonable to expect people who wish to ride a half mile or a mile to pay a fare that will make up for the deficit caused by hauling another passenger ten miles. The introduction of the zone system with a low minimum fare will cause a tremendous increase in the number of passengers carried, and this will increase the number of cars required, which will still further increase the amount of traffic, and the receipts will increase proportionally.

It was feared that the introduction of the metal filament lamp with its low power consumption per candle-power, as compared with the carbon lamp, would seriously handicap the electric light companies by cutting down their power sales. The results have been just the opposite. People who have become used to paying a certain amount for a given commodity will usually continue to pay as much, even though they can get a great deal more for the same amount. Those who are not using the commodity at all will be attracted by the lower rate. This will be the case with the application of the zone system. Few will cut down their total payments to the street car company but thousands will contribute who do not do so at the present high rates.

It is one of the most encouraging signs of the times that one of the largest street railway systems in the country has adopted the graduated fare system. The Public Service Corporation of New Jersey is trying this plan, as it was found to be the best way in which to operate their lines and secure the necessary revenue. The system they have introduced calls for an initial fare of 3c for the first one mile zone, with an extra 2c for every other zone or fraction of a zone in which the ride takes place. A very simple plan has been worked out for collecting fares, and it is believed that after a short time this will be just as easy to handle as the present flat rate system. The transfer system, with its abuses, is eliminated; passengers pay for what they get and get what they pay for. While this scheme undoubtedly compels long haul passengers to pay more for their rides, it is only simple justice that they should do so. The number of short haul passengers will be enormously increased and the street railway company will have its reputation enhanced in the community because it is serving all of the people at a rate which is commensurate with the service rendered. Before deciding on the rates or lengths of zones for other cities, it is, of course, essential that a study be made of local conditions.

It has been said that the zone system tends towards great congestion in the cities. It would be hard to conceive of greater congestion than has been built up in New York City and other large cities using the flat rate system, and we doubt very much if the argument has any basis for its existence. It is founded largely on the idea that everyone wishes to do business in the same little congested area and utterly disregards the number of small business centers which are scattered throughout every large city where people can do their marketing and congregate for various other purposes.

If the flat rate system is to be maintained for the good of the city it should be done by taxing the community to help pay the cost of bringing in passengers from the suburban districts. This tax should be paid by the entire city rather than by the short haul passengers. The results of the introduction of the zone system in New Jersey will undoubtedly be watched with the greatest interest by all street railway people.

Mutuality of Interests in Practice

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New York State Railways

AT THE PRESENT time, when a general effort is being made to find a way to synchronize fixed and inflexible man-made laws which govern street railway fares with automatically adjusting and flexible economic laws which govern operating expenses, it has been found necessary by city and railway company officials to resort to many expedients in order to permit electric railways to meet expenses and prevent bankruptcy. One of these methods was adopted by the city of Syracuse in order to meet the question of the high cost of railway credit and thereby permit street

improvements to be made in the city.

In the fall of 1918 the street railway company in the city of Syracuse was authorized by the Public Service Commission to collect a fare of six cents. This resulted in splendid increases in receipts and partially met the increase in the cost of wages and material which has taken place in the last two years. During last winter, the city decided that it was necessary to renew the pavements in a large number of streets on many of which were street railway tracks, the total cost of this work to the railway company being approximately $400 000. While the increase in receipts from the six cent fare was greater than had been expected, it would not provide funds with which to carry on a reconstruction program. Money could not be obtained under present conditions from the sale of securities nor from the use of credit at the banks and it was, therefore, necessary to provide other means of raising the money to meet the cost of the program which the city was proposing, or not undertake it at all. With this in view an application was made to the Public Service Commission for consent to make a charge of one cent for transfers in addition to the six cent fare which was already being collected. As a result of this application, the city made a counter proposition under the terms of which the city would undertake to extend its credit to the railway company in financing the improvements. The plan which was proposed involved an amendment to the present franchise by which the company permitted the city to contract the construction of tracks in the streets as well as the pavements and assess the cost of such work to the railway company over a period of ten years in the same manner that paving assessments are made.

The practical working out of the plan has been that the railway company is receiving the contracts from the city for doing the work of reconstructing its tracks and in carrying on the work the railway company is financing the payrolls and material costs for a period of one month, at the end of which time the city is reimbursing the company for the money expended during the previous month and will assess this against the company, to be paid for in ten annual installments.

Under this plan, money is being borrowed from the city with no discount and at five percent interest. The city is getting the benefit of having the improvements, which they wish made, completed and the railway company is getting the benefit of reduced operating expenses on account of better track conditions, is having ten years in which to pay for the expenditure, is getting the money with no discount and at a rate of interest of five percent.

A plan of this sort is merely indicative of the fact that the time is not far distant when there will be a full and active realization by municipalities and railway companies of the mutuality of their interests in having the railway company financially successful, which condition is necessary for the progressive operation of any business.

The Future of the Birney Safety Car

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Stone & Webster

THE BIRNEY safety car has a distinct place in city transportation. Until the advent of the jitney, five years ago, the tendency in car construction had been gradually but steadily toward larger units. The short wheel base, single truck car was rough riding and objectionable to the public. Therefore the demand from city authorities and the public for heavy double truck equipment for all lines under all conditions of traffic. These large cars, with the fast increasing vehicular traffic and street congestion, developed one of the worst ills in street railway transportation—slow service.

The public is primarily interested, in the order named, in four things, reliability—speed—comfort—safety. The speed of city cars, compared to other modes of paid-for transportation, is the slowest of all. The jitney brought this fact clearly home and conclusively showed that the first element of street car transportation—speed—must be provided or the loss in earnings of street railways would be enormous. These conditions were primarily responsible for the conception of the Birney safety car.

What has this type of car accomplished? It has, wherever properly used, completely revolutionized old methods of city transportation. Every phase of its operation has been successful. It has created new traffic. The details of its use throughout the country are too well known to call for comment in this brief article. Any type of car used in city transportation that fails to promote the four elements recited—reliability—speed—comfort—safety—is a step in the wrong direction. All these elements are combined in the safety car. It is the biggest step forward since the days of electrification. The car which actually gives our public the above four elements satisfies them, as has been demonstrated wherever the Birney car is in use.

A type of car which occupies such a distinct place in city transportation today is bound to extend its usefulness until such time as the development of the art produces something better. Those interested in street railways, whether in the management or through investment, would perform a real service both to the interests which they represent and to the public which they are undertaking to serve by becoming familiar with the various advantages which the Birney safety car offers.

Momentum of Custom

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WHILE INERTIA and momentum are usually thought of in connection with material or physical objects, like characteristics obtain in the case of the customs and the attitude of people (collectively more than individually). The greater the mass, the

greater the inertia or momentum as the case may be. Accordingly, the larger the population affected (the rule appears to be) the more difficult it is to retard or accelerate any idea or change in viewpoint on subjects which may disturb or alter in any way the conveniences that have been enjoyed or rates that have heretofore been paid, unless the new condition be distinctly favorable to the public either in the way of increased accommodations or lowered charges for a given service, or both. Although this analogy may seem trite and commonplace, it applies with particular force to the street railway industry. When one reflects upon the matter, it is realized that there are few if any other businesses which are confronted with the like problem of measuring or dividing the service into convenient units, distances or other means of determining rates. In almost every other form of business, the problem of the fair quantitative treatment of the product or service is comparatively simple but the street railway virtually stands alone in this respect in that it is very difficult in actual operation to separate or classify the extent of service of which each individual patron avails himself and at the same time vary the charge accordingly. Suggestions have been made that a primary readiness-to-serve or what might logically be termed "entrance" charge might be made as the passenger boards the car, which may cover in addition a predetermined and limited distance, and a second or riding distance charge depending upon the length of ride. But due to the complication in the registration and collection in such a variable scale of fares, a plan of this kind will only come into general use in the larger centers of population through a rather slow process of evolution. In the meantime, operating companies will be compelled to resort to a workable present-day solution which will differentiate in some equitable and practical way between the short and long haul riders, providing for continuity and overlapping of the riding distances of different passengers.

Changes in the basis of charging for street railway service were slow at first. In the majority of localities, however, increased fares of one kind or another have now been installed, although a few municipalities have succeeded in still restraining the operating companies from raising their rates. This hindrance which the street railways encountered is largely responsible for the present deplorable financial condition of many operating companies. Unfortunately when the street railway business was started, the possibility of such a depreciated value of currency was not contemplated. Along with the dollar, the nickel fare has shrunk to about 50 percent of its former worth. In other words, the revenue resulting from the nickel collection will purchase in the form of labor, materials and supplies but one-half of the amount which it did in pre-war days. Owing to the growth of the community served, the urban street railway situation was further aggravated by the usual co-extension of the single fare limit with the new boundaries of the residential and manufacturing area. Moreover, more commodious and frequent service has been exacted in many communities, all of which the majority of companies would in all probability have provided voluntarily if they had been free to prosecute their business along proper lines and thus secured means sufficient to have enabled them to meet all reasonable demands of the service.

For several decades the street railways have been the football of politics. Consequently antagonistic sentiment against the railways was engendered. The friction between the companies and its patrons resulting had the final effect of so handicapping such companies that they naturally were unable to meet shifting conditions. To offset the serious position into which a great many companies were thus forced, desperate effort had to be made to obtain relief. The public has been slow in yielding their consent to any general advances in rates. The Public Service Commissions, on the other hand, have acted wisely in granting their approval of increased charges in the cases over which they have had jurisdiction.

Notwithstanding the temporary improvements which have thus been realized, a vast amount of work is still to be accomplished by the railway utilities. The needs of the companies and the demands of the public must of course be properly reconciled. Due to the inertia inherent in the task, no time should be lost in making a critical study, where necessary, of all of the underlying factors of the business and a sincere attempt should be made to evolve a system of fares which will establish justice all around. Evidently the company on the one hand must have sufficient earnings to meet its due financial obligations—being deprived of which it rapidly reaches an exhausted and crippled state—and on the other hand the community must have adequate transportation facilities, together with such a system of rates as will not superinduce any congested living conditions but contrarily may promote the development of the suburban districts. Manifestly this latter feature represents one of the most delicate phases of the problem. The riding habit of the short haul passenger must be encouraged but this is impossible for the company to do if it must make too many sacrifices in behalf of the long distance rider. An obvious aid in such cases is for the municipalities to lift the burden of taxes, street paving and other assessments, thereby leaving the ultimate payer—the car rider—to defray only such items of expense as are incident to transportation. Many methods of solving the situation have been tried and a number of them are working satisfactorily. No two communities are alike in all respects and each locality must be analyzed and treated in an individual sense.

What has preceded applies in the main to urban railways, but the interurban class has similar problems although more easily surmountable. The large question with the interurban roads has been the selection between varying the zone distances or the zone rate of fare. Here the best interest of both the utility and the travel-

ling public must be weighed deliberately and at the same time the force of custom is not to be overlooked.

It is therefore apparent that the available data on all new plans should be gathered for the benefit of the industry as a whole. The various factors to be reckoned with are geographical, topographical, distributional, physical, political, psychological and financial, besides those which distinctly come within the domain of management and operation. In applying a revised and correct rate method on any property involving as it may an appreciable change in the habits and customs of the car riders, it is plain that in order to avoid unpleasantness and criticism, intelligent direction must be given to bringing the people as a body to a full comprehension of all equities and properties in the case. In view of the natural opposition, the task is manifestly no simple one, hence an extended period of time may necessarily be consumed in its accomplishment. Plainly, it is vital that we seize advantage of the present moment to effect due adjustments and to issue befitting propaganda.

Co-operation between Operators, Car Builders and Equipment Manufacturers

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THE GREAT advantages to the railway industry of having the car operators, car builders and equipment manufacturers working together in close harmony should be selfevident. A typical example of the results obtainable is shown in the development, manufacture and, incidentally, the promotion of the light weight safety car. On many lines, where a deficit was shown with the operation of the old-time two-men heavy-weight car, these same lines, now equipped with the safety car, are showing a good net profit. Development of this car would have been almost an impossibility without the working together of car builders and equipment manufacturers to produce a complete car in accordance with the ideas of the inventor.

But a short time ago, practically every master mechanic had his own ideas about how a car should be built, and there was no such thing as a standard car with any car manufacturer. This meant that, on each order, the car builder's designer must make new plans and specifications, and in many cases the completed car did not come within the weight specified. After the order for the car was placed, it sometimes took from two or three months before complete data could be interchanged between the car builder and the equipment manufacturer. Upon receiving the car specifications, the equipment manufacturer tried to have one of the many styles of motors they were making installed to the best advantage, in some cases having a motor exactly suitable, in other cases motors that were too large and on others motors that, upon the car being put into service, proved to be too small. The ultimate result was that the cars and equipments cost the railway companies a much larger amount than they should, had the cars and equipments been designed for each other.

Under the old practice, it was impossible to have quantity production, as no company could stock cars; and due to the large number and variety of railway equipments, it was impossible to stock, to any extent, railway motors. Even if the motors could be had within a short time and some gears were in stock, the gear ratio was probably wrong, necessitating special orders, and in some cases considerable delay. Without quantity production the cost of all manufactured articles is unquestionably high, and this cost ultimately must be borne by the railway companies.

Another exceedingly important matter is the question of delivery. With the present close working together of the car builder and the equipment manufacturer, deliveries can be made in about one-half the time required in the past, thus allowing the railway companies to put cars that can become revenue producers into operation from two to three months earlier than under the older methods.

Without a close working arrangement between the car builder and the equipment manufacturer, there is small prospect of either of them making a reasonable, if any, profit on the manufactured article; while with close co-operation, a reasonable profit can be made by the different manufacturers, and the railway companies will obtain a much superior article, at a considerable saving.

Looking backward and viewing the time of the heavy weight of cars, with the large motors necessary to operate them, and seeing the necessity of putting in 90 to 110 lb. rails, with all of the other costly work, one can readily see the great saving that could have been made if the manufacturers had worked closely together, showing to the railway companies the great advantages of standardization, thus enabling them not only to cut down the cost of the car, but of the track work, overhead lines, power house equipment and, last but not least, the item of labor. Reports now being received from superintendents, electrical engineers and master mechanics tend to show that the saving in maintenance of the track, power house equipment, overhead lines, etc., is almost in proportion to the weight of the car.

It seems evident that, if a close working arrangement could have been had in the past between the car builder and the equipment manufacturer as we have at present, many of the ills that street railway properties are now heir to could have been avoided. The greatest question at the present time before the public is undoubtedly the League of Nations, and with a similar idea of organized co-operation in view it would seem that this is a very opportune time for the entire electrical industry, comprising central stations, street railways, manufacturers, jobbers, dealer-contractors, engineers, etc., to take steps to have one unified organization, all working together for the benefit of the electrical industry as a whole.

Electric Railway Passenger and Freight Transportation

C. E. Morgan
General Superintendent,
Michigan Railway Company

ELECTRIC railways have one product or commodity to sell, that is transportation. To the life of the industrial world transportation is as vital as sleep is to the human being, and without sleep we human beings would soon perish. Likewise, without transportation, our industrial and commercial activities would cease, and the population of some of our larger cities, depending solely upon transportation for food supplies, would reach the point of starvation within sixty hours.

Transportation is a factor that enters into every line of business and it is the duty of any transportation company to move their passengers and freight in safety, comfort and despatch between any two points reached by their own, or connecting lines. The electric railways have become an important factor in the transportation business, and are so recognized by the Government. At present many electric railway operators are overlooking the opportunity to take advantage of securing additional revenue from the transportation of freight commodities. Primarily, electric railways were built as passenger-carrying lines, starting first with the extended street car line and later, through extensions and consolidations and traffic arrangements with connecting lines, they have been able to extend their service beyond the original promotor's dreams. If as much attention was given to the development of the freight service as was originally given to the hauling of passengers, many electric railways would be in much better financial condition at this time.

Through a well organized traffic and operating department, the revenue derived from transportation of freight commodities could be materially increased on every line, even with the present freight-handling facilities found on the average line. The electric railway, with its heavy capital investment and overhead expense on which interest is accruing on a twenty-four hour per day basis, is not operated, with a few exceptions, to the fullest capacity, inasmuch as it does not operate either passenger or freight service between the hours of midnight and 5 A.M. and, in fact, there are few passenger trains operated, on what are commonly known as interurban lines, after 7 P.M. that earn enough revenue to pay the expense of their operation. Yet, with these conditions there are many instances where the freight service furnished by electric railways is rendered wholly between the hours of 5 A.M. and 9 P.M.

Traffic and operating officials, in making freight schedules, should bear in mind that any commodity transported over their lines should be handled in the shortest time possible from the originating point to destination and, inasmuch as the majority of the freight shipments are delivered to the freight houses of the transportation companies within the last two hours of closing time of receiving such freight, facilities at such receiving points and terminals should be such as to avoid taking this freight from the trucks and placing it in the freight house. With the one handling, it should be taken from the receiving door and trucked directly into the car in which it is to be transported to destination, thus eliminating extra handling. It costs 30 cents or more per ton for each ton handled through the average freight house, and with the high cost of labor and material, it is the duty of every transportation officer or employee to eliminate any extra work or the delays in handling such commodities.

FIG. 1—SWITCHING IN GRAND RAPIDS YARDS
Michigan Railway Company.

As above mentioned, few electric railways attempt to utilize the portion of the twenty-four hours that their plant is not productive. The management of electric railways should develop their freight business to such a point by doing the bulk of their freight business at night, when freight trains could be handled on the line with the least delay and interruption to passenger ser-

vice, for when freight trains, particularly the local freight trains, are operated on a line that attempts to give frequent service, the freight trains are not handled efficiently, due to the time consumed by such trains in clearing time of passenger trains, whereas, if operated when there are few if any passenger trains, considerable time is saved by the freight trains on account of its being unnecessary for them to take sidings.

A great many of the railway operators are overlooking the carload business, and it is surprising how many carload shipments can be secured and handled with the regular freight schedule, it being the duty of such operators to keep their freight trains loaded as well as their motor cars—but motors should not be overloaded.

Transportation companies should bear in mind that they are doing business at some other person or firm's loss in that when any commodity is in transit between two points no one is receiving any return on the value of such commodity until it has reached its destination and been received by the consignee. If the commodity shipped by the consignor is taken from his plant at the close of his day's business and transported during the night, or while his plant as well as

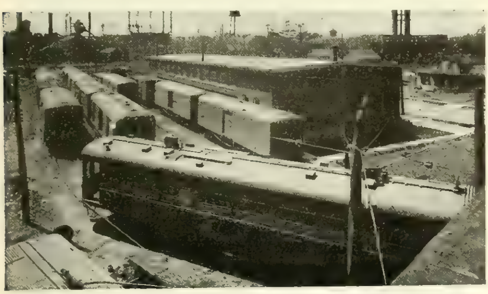

FIG. 2—BATTLE CREEK FREIGHT STATION AND YARDS

that of the consignee is idle, and delivery is made early the next morning to the consignee, then the transportation company has given the correct service and by such service has not added to the capital investment required by the consignor as working capital. However, if this shipment had been received in the evening, and was not delivered until the second morning, then the transportation company has caused the consignor to double his working capital in case all his product was moved over or between the points where over-night service was not given. Or where the electric railway does not start their freight trains out until the morning of the next day and such freight does not reach its destination until late in the afternoon of the same day, this likewise results in a delay of twenty-four hours.

It is true there are many electric railways whose freight business does not warrant operating power plants with which to supply power to their freight motors during the time that passenger service is not in operation, and in many cases, this has kept electric railways from giving the over-night service, whereas, if the shippers knew that they could secure such over-night service on the electric railway, the freight service could be developed to a point where it would warrant running the power plant on a twenty-four hour basis. Further, the operation of the freight trains, particularly during the rush hour periods has given the power plant a peak load that would have been reduced considerably if the freight trains were operated at other times than during these rush hours. On account of this it has been necessary in many instances to add power house equipment to take care of these peaks at an additional expense.

The local conditions on the respective lines must be considered carefully in laying out freight schedules. It is often necessary to operate some freight trains during the daytime, to take care of perishable freight, milk shipments, etc.

Night service enables transportation companies to work freight equipment more frequently and requires less labor at terminal warehouses and will enable the handling of considerably more freight through the same warehouse, due to having the cars at the various stations, which should be unloaded the first thing in the morning when few outbound shipments are received and the cars will be made empty so that when the rush hour is reached in the receiving time, freight with one handling can be put directly into the cars. Otherwise, if the freight trains were operated during the day time, these cars would not be available, and the freight would either have to be floored in the warehouse, awaiting cars, or it would be necessary to make an investment in additional rolling stock, which in turn would require additional track facilities.

There are many electric lines connecting with each other, that by making joint traffic arrangements could inaugurate through service between more distant points on respective lines, and by inaugurating through freight schedules as well as passenger service, the revenues of the various roads joining in the through service would be materially increased and, at the same time would eliminate the transferring of freight at the various terminals. It is surprising how much additional car load business can be done by such an arrangement, and it has been the experience of electric railways that, as soon as such through service has been inaugurated, it has shortly outgrown the facilities, and when this point has been reached careful and prompt consideration should be given to increasing particularly the warehouse and track facilities.

In the Central States, the electric railways have in the past few years given more attention to the freight business. Instead of the freight business being a side issue, with revenues amounting to eight to ten per cent of the gross revenue, they have, by through routes and overnight service, built up the freight business between the various points reached by such lines until the freight revenue has become an important factor in the earnings of such properties.

As an example of what can be done in operating through service, there is now through overnight service between Akron, Ohio and Detroit, Michigan, a distance of 213 miles, between Dayton and Troy, Ohio to Detroit, Michigan, a distance of 219 miles, between Dayton and Indianapolis, 108 miles, Indianapolis and Louisville, Ky., 117 miles, Indianapolis and Fort Wayne, Ind. 136 miles, between Grand Rapids and Detroit, Michigan 184 miles, between Kalamazoo, and Detroit, 146 miles, between Lansing and Detroit, 113 miles, between Detroit and Bay City 116 miles. The above mentioned service being through service operated over two or more electric railways. In connection with the Graham & Morton Transportation Company, the Michigan Railway gives overnight service between points on their line, particularly Grand Rapids and Chicago, a distance of 143 miles. The above business is handled mostly in through express cars, commonly called trailers, and in some cases provides for through motor car operation.

A great many lines in the Central States, particularly Michigan, make delivery between all points on their line overnight. This is service with which even the express companies operating on the steam lines cannot compete. The additional competition now before the electric railways, in the form of the gasoline motor truck, makes it even more necessary to give greater attention to the handling of freight.

FIG. 3—FREIGHT STATION AT GRAND RAPIDS

Another important matter that should not be overlooked in connection with operating freight trains at night, is that so doing will eliminate a great deal of the objections raised by municipalities to freight trains operating over their streets during the day time, which also interferes more or less with city car operation. By operating through these towns at night, especially after 11 P.M. there is hardly any objection raised, and this also permits the operation of longer freight trains, with a consequent less delay.

The traffic department should be properly organized, with through rates and proper solicitation of both freight and passenger business. It should have solicitors that are not merely order takers but can point out to the shippers and patrons of the service that the electric railways can save the shippers money by giving prompt service. The freight business is really handled with more prompt dispatch than that of the express companies at freight rates, and such solicitors should go into details with prospective shippers and keep a lookout for business at all times and thoroughly explain how the electric railways, by giving overnight service, can reduce their working capital or interest charges. In this connection the operating department must fully co-operate with the traffic department to bring about service that will be satisfactory to the patrons of the line.

The laying out of schedules is not a question altogether of making high speed—it is a question of regularity of the service—and such schedules should be elastic enough to take care of ordinary operating delays, as it is regularity of service that wins approval with the shippers.

Passenger schedules of electric railways can materially be improved, particularly as to connections between various lines, and where possible through service should be operated, running through over various lines. In building up train schedules, it is not always necessary to schedule them as fast as they can run, as the general public do not like a train to be late, it being much better to build a schedule that can be maintained, even though it consumes more time, as it is the regularity of the service that attracts the business to the road.

The electric railways at this particular time have an opportunity in the transportation of freight, that should not be overlooked, largely due to the Government controlling the steam lines, practically eliminating the competition between them and stopping the solicitation by such lines, and now is the time to take advantage of such conditions and educate the people to ship their freight by the electric railways. At the same time there is a noticeable change in the attitude of the steam lines towards the interchanging of business between steam and electric roads. There are also many cases where factories could be located on electric railway lines, connections made with steam lines and switching arrangements made whereby the revenue of the electric railway could be materially increased.

To secure the greatest efficiency from the equipment on electric railways and to insure its prompt movement, the distribution and handling of the cars are important factors, keeping in mind the balancing of the freight movements in order to eliminate the deadheading of empty equipment. This cannot be handled satisfactorily by allowing agents or division traffic or operating officials to handle their own cars. This work should be assigned to someone at a central point, so that the movement of all cars on all divisions can be followed closely. Then, as soon as they are unloaded, they can be placed where another load will be waiting for them with the least possible delay.

The average earning per freight car per day on steam lines is approximately $3 with an average mileage movement of 10 miles per day, while on electric railways the earnings per day have reached as high as $36 per day for every car operated, and the average mileage per day made by such cars is nearly 57 miles per day, this being on property where overnight service prevails.

The motor trucks should be made to feed the elec-

tric railway line service, instead of being allowed to compete with it. The possibility for increased revenue through the freight that will be brought to your lines by entering into contract with such trucking concerns operating to points not reached by your line, or in territories not served by either steam or electric railways, is worth looking into, even going so far as to arrange through rates and filing joint tariffs with such motor truck routes. The Michigan Railway Company have such working arrangements with motor truck lines, and have found it to be quite advantageous both in keeping down truck competition and increasing freight revenues.

Many railways, as their freight business has grown, have pressed into the freight service motor equipment from the passenger service. Others make the mistake of purchasing new equipment with gear ratios as high as they use on their passenger equipment. This results in abnormal power consumption and the limiting of such motors to a lighter tonnage, which involves higher op-

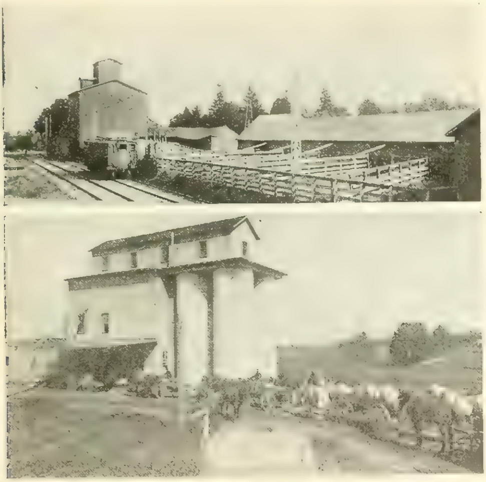

FIG. 4 STOCK YARDS AND ELEVATORS ON LINES OF MICHIGAN RAILWAY COMPANY

erating expenses as the business increases, due to the necessity of adding additional units or additional motor cars, and at the same time raising the cost of maintenance of such equipment.

It is a well-known fact that the speed varies inversely as the ratio of gear teeth to pinion teeth, and that the tractive effort varies directly as the ratio and with an increase in speed, at any given current, the tractive effort proportionally decreases. A freight motor car adapted for single car operation or able to handle from one up to five trailers, is one of the most valuable types of motive power on electric railways, particularly if this unit is used on local freight runs, where the motor can be loaded and used as the peddler for way stations. On account of using such cars for switching movements quite frequently, they should also be equipped with motors and control of sufficient capacity to stand the heavy duties imposed upon them, particularly in switching where an interchange is made with steam lines, as it is necessary at times to handle a cut of cars that ordinarily would overload the average freight motor. With a high gear ratio, such a motor car would not be able to handle such a train without the slipping of wheels and the overheating of resistors, motors, etc. There are many cases where electric locomotives meet the service conditions better than the freight motor car that carries a body that can be loaded with freight.

It has been the general experience of electric railway operators, who have realized the possibility of freight business and the revenue derived therefrom, that in laying out terminals, freight houses, track facilities and equipment, by the time they have such facilities completed and equipped for service, invariably the business has grown beyond the facilities they had just completed. This demonstrates that electric railway interests have never fully awakened to the possibilities of freight transportation. We find further, that some of the electric railways are satisfied to handle only certain commodities of freight, while it has been found that a railway that steps out after all classes of business both less than car load and car load shipments, and not any certain commodities, is generally the railway with the largest net receipts from freight transportation.

Another source of revenue that has been overlooked by a great many railways is the handling of what is commonly known as despatch freight on passenger cars. When the Government took over the steam railroads and shortly consolidated the express companies, many electric railways found themselves without the old line express companies operating over their lines, and in a few cases old line express companies only operate on electric railways to points that could not be reached by steam lines, resulting in the loss of receipts to the electric railway. There is quite a demand for movement of freight shipments at times other than when the regular freight service is in operation, and a good many of the lines in the Central States have inaugurated the so-called despatch freight system, whereby a shipper can have his shipment handled on a passenger train, as most cars in the Central States are equipped with baggage compartment. Such a shipment is usually handled at a rate of about double the first class freight rate, and inasmuch as it is necessary to have the station help already employed to handle baggage, sell tickets, etc., these same employees can handle this despatch freight without any extra expense. Even though making only the station deliveries, not operating any wagon, pick up, or delivery service, the consignees are able to secure their shipments in less time than if they had shipped by old line express companies. The lines that have gone into this have found it very profitable, more than offseting the loss experienced by the loss of the old line express business.

To develop the freight business, it is necessary to analyze the territory to be served, not only in the terri-

tory reached by your own line but other lines as well, to provide proper facilities in the way of stations, tracks, sidings, etc., to arrange a well-organized traffic department, to provide proper motive power and rolling stock, especially trailer freight cars, and to follow publicity by personal solicitation, and above all to see that the service is regular and meets the demands of the shippers.

Service with the Safety Type Car

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San Francisco District Office,
Westinghouse Electric & Mfg. Company

THERE are in the United States approximately 47 500 miles of electric railway lines, representing an investment of about five billion dollars. This comprises elevated, surface and subway lines furnishing city, suburban, interurban and heavy traction rapid transit to the centers of population. In 1917 this industry produced a net income of $41 800 000. In 1918 although handling over eleven billion passengers the net income was $10 700 000. Among the causes contributing to this shrinkage in earnings the following are generally known:—

1—The increase in operating expense due to the higher wage rate and material cost, brought about by the great world war.

2—The failure of increases in fare rates granted to increase gross earnings sufficiently to overcome high operating expense and return the pre-war net income.

3—Competition by the privately owned automobile, the jitney and the motor bus.

The condition of the electric railway industry due to these causes has become so serious that the Commission on Electric Railways, appointed by President Wilson, has been collecting data preliminary to definite action being taken for the preservation of this very necessary branch of transportation service. Few trolley patrons who shout "watered stock" whenever a suggestion is made that an increased fare may be necessary, realize that 60 traction companies comprising 763 miles of track and equipment have already been dismantled because a receiver could not make them pay the cost of operation. Of course some of these lines should never have been built, but there are also at the present time 62 other companies operating 6000 miles of electric lines in the hands of receivers, including such properties as the Brooklyn Rapid Transit System. The Boston Elevated Railway Company is operating with earnings guaranteed by the commonwealth; a ten cent trolley fare barely earning a small percent on the property valuation.

In the State of California, never more prosperous industrially than at the present time, the electric railway companies, in spite of being favored with a good operating climate and reasonable power costs have suffered seriously from the causes enumerated. To illustrate in Table I is given data on four railway companies, each with gross receipts between $200 000 and $500 000 a year, operating a total of 140 cars daily in four cities of this state, having a combined population of about 150 000. This operating data was reported to the Railroad Commissions for the years 1914 and 1918 and gives a very good idea of what is actually taking place throughout the country.

TABLE I—TOTAL OPERATING DATA OF FOUR CLASS B ELECTRIC RAILWAY COMPANIES IN CALIFORNIA

Year	1914	1918	Relative Percent
Car mileage	6 344 026.	7 153 452.	112.8
Total passengers	29 025 090.	28 135 101.	97.0
Average passengers per car mile	4.57	3.92	85.9
Total operating revenue	$1 331 472.96	$1 320 074.90	99.25
Per car mile	0.2095	0.1841	87.8
Per passenger	0.0458	0.0469	102.2
Total operating expense	$850 406.48	$1 064 501.15	125.2
Per car mile	0.1339	0.1476	110.
Per passenger	0.0293	0.0378	129.
Total net operating revenue	$481 066.48	$255 573.75	53.2
Per car mile	0.0750	0.0369	48.7
Per passenger	0.0166	0.0090	53.3
Operating ratio, percent	63.8	80.7	126.2
Taxes and interest	$289 103.14	$363 015.76	125.6

The points to be noted particularly from Table I are as follows:—

1—Although the total car mileage or service was increased 12.8 percent in 1918 over 1914, the total passengers were three percent less in 1918 than in 1914. This indicates the effect of the automobile.

2—The average passengers per car mile of service in 1918 were only 85.9 percent of the 1914 figure. The total operating revenue decreased only three-fourth percent due to several of the companies having a six cent fare in 1918.

3—The total operating expense increased in 1918, 25.2 percent over the 1914 figure.

4—The net operating revenue in 1918 was 53.2 percent of the 1914 amount.

5—The operating ratio increased 26.2 percent in 1918 over the 1914 figure of 63.8 percent.

6—The taxes and interest item increased from $289 103 to $363 015 in 1918 or 25.6 percent. Practically all of this increase is in taxes.

These are the conditions that confront the present carefully operated street railway systems in four cities in California, each of sufficient size that its inhabitants require public utility transportation between different parts of the city. Two alternatives present themselves;

1—Increase the fare rate to provide the necessary gross income or.

2—Reduce operating expenses.

Three of these companies now receive a six cent fare. One of them has had serious jitney competition on its best line since the fare was raised to six cents. It is further obvious that in small cities where the average ride is comparatively short, the higher the fare

*From a paper before the Pacific Railway Club, Oakland, Cal., Aug. 14, 1919

rate for the same service the larger the number of patrons who will walk. This is particularly so in cities where the trolley service is 10 to 15 minutes between cars, and it is frequently nearly as quick to walk as to wait for a car and ride. On some small properties a fare increase has actually resulted in a decrease in gross receipts.

The second alternative, namely by reducing operating expenses involves reduction of platform expense, track or equipment maintenance, power consumed, the accident or claims account and general office expense. This is best accomplished with the safety type car.

The Safety Type Car was developed almost entirely by one of the largest public utility syndicates in the United States, the Stone and Webser Company, as an operating necessity to provide increased service to overcome jitney competition at decreased gross operating expense, through better operating effeciency; in other words to furnish better service at lower cost.

FIG. 1—SAFETY CAR IN SACRAMENTO, CAL.

This seven ton high speed car, with special safety devices for one man operation, has been an absolute success from the standpoint of the riding public and the operating companies. The car seats 32 persons comfortably. Although used mainly in cities of less than 100 000 population, its use is being extended rapidly to the larger cities. The Brooklyn Rapid Transit System recently ordered 200, making 212 in service. There are now over 2300 safety cars in service in the United States.

To illustrate the economies involved, take a line 4.44 miles long on which a ten minute service is furnished 19 hours per day, with two man operated cars, weighing light 20.25 tons each and seating 48 passengers. The average rate of pay for platform time is 45 cents per hour per man. The present schedule speed including stops is 10.65 miles per hour and five cars are required for the 1012 daily car mile service. Duplicating this service with five 7-ton safety cars requiring one operator per car, at 50 cents per hour, the saving in platform expense is $13 850 per year. The power expense is reduced by the substitution of the lighter weight car $24.65 per day or $9000 per year. Rolling equipment maintenance, at present two cents per car mile, will be reduced on account of the lighter weight modern equipment, 24 inch wheels instead of 30 inch wheels, etc., to a figure of 1.2 cents per car mile, which is conservative, considering that some of Eastern properties have operated these cars for 0.85 cent per car mile. On this basis the equipment maintenance would be reduced $2990 per year.

The total saving due to safety car operation on these accounts would be $25 840 per year. The investment involved would be approximately six cars at $6100 each delivered, which includes one spare, or $36 600. Deducting six percent interest on the investment would leave $23 644 as a net yearly return, which is 64.7 percent on the investment and would return the full amount in 1.55 years.

However it is possible with the safety car in many cases to reduce the headway slightly with the same number of cars, by increasing the schedule speed, due to the higher rate of acceleration of the light weight car. On the line referred to, traffic conditions permitting, the headway could be reduced from 10 to 9 minutes, furnishing 108 car miles more service daily. In this case the platform saving would remain the same but there would be small additional power and maintenance expense due to increased service. The total saving on this basis would be $24 800 per year or a net saving after interest is deducted of $22 704 per year, which is 63 percent on the investment, requiring 1.58 years to repay.

Electric railway companies generally have known that improved service such as shorter intervals between cars increases riding. This serves to combat the private owned automobile and jitney competition, and reduces the tendency of the riding public, particularly in small cities, to acquire the walking habit. In larger cities the headways are generally satisfactory in the business districts where the short riding traffic is available. With the safety car it has been found possible to give the public improved headways at less than the cost of operating old cars at longer headways.

To cite a specific case; on the line previously referred to, it is possible with one additional safety car, or a total of six, to reduce the headway from 10 minutes to 7.5 minutes, increasing the service 33 percent and operate for $19 150 per year less than the present cost of 10 minute service with old equipment. The net return per year of $16 588, after deducting interest, represents 38.9 percent on the investment of $42 700 for seven safety cars, and will return the investment in approximately 2.57 years without making any allowance for increased receipts.

Summing up the advantage of the safety car over old style operation, the following definite improvements have been noted by electric railway operating managers.

1—Elimination of step accidents.

2—Reduction in accidents of a general nature, due to the facility of handling cars.

3—Faster schedule speed and increased service with the same number of cars. For instance headways reduced from 10 to 9 minutes or from 8 to 7 minutes.

4—Successful competition with the jitney bus due to the possibility of shorter intervals between cars or increased service at reduced cost.

5—Satisfaction of the local city governments, as evidenced by requests for extension of safety car service in many communities.

6—Satisfaction on the part of the operators, on account on an increased rate of pay.

7—Saving in power, which for practical purposes is proportional to the difference in weight of the equipments.

8—Reduction in rolling equipment maintenance.

9—Increased receipts on many lines, due to the prepayment feature being installed with the safety car.

10—Last and most important, satisfaction of the riding public, both expressed by word and indicated by increased patronage.

By way of conclusion it may be safely said that the safety car is without question the greatest new developement in the electric traction industry during the past five years, in that it operates to give improved service to the public, and contributes to the permanence of the electric transportation business.

Municipal Railway Operation
At Seattle, Washington

Thomas F. Murphine
Supt. of Public Utilities,
City of Seattle

On April 1st of this year the City of Seattle, by the purchase of the street railway properties of the Puget Sound Traction, Light & Power Company, came into possession of approximately 206 miles of street railway track and overhead system, 540 street cars, 81 pieces of real estate and a variety of buildings, car barns and shops, freight sheds, machinery, tools and equipment, and a stock of supplies. Certain portions of this property were appraised by various engineers and real estate appraisers. The street cars were valued at \$2 500 000; the commercial real estate at \$540 000; the buildings, car barns, shops and freight sheds at \$528 980; the machinery, tools and equipment at \$500 000; and the stock of supplies at \$350 000. The railway track and overhead system, some 206 equivalent single track miles, was not physically appraised at this time, but from former appraisals made by engineers of the Public Service Commission of the State of Washington and by comparison with the cost of construction of like track by the City of Seattle and the City of San Francisco, a value of \$11 683 966.06 was placed by this department.

The total purchase price by the City of the street railway properties was \$15 000 000 in utility bonds, payable in annual installments of \$833 000 beginning March 1, 1922, with interest on the total amount at 5 percent per annum, payable semi-annually. Prior to this purchase the City was operating 23 miles of street railway and had under construction 3 1-3 miles of elevated railway through the industrial district.

The immediate causes that led up to the purchase by the City of Seattle of the railway properties of the private company were:—

1—The service given by the company was totally inadequate. Shipbuilding and other war industries were suffering from lack of transportation.

2—The company was demanding an increase in fares of one cent with one cent additional for transfers.

3—The company was further demanding to be relieved from all franchise obligations.

4—The employees of the private company were not being paid a living wage.

The city officials of Seattle maintained that with the relief from franchise obligations adequate service could be given and the fare kept at five cents. The City has now operated its railway system for the first quarter of the year 1919, maintaining a five cent fare and free universal transfers, and a brief resume or financial statement of operating receipts and expenses for the first quarter with the comparison of the corresponding quarter of last year will be interesting. Our experience for the first three months, however, ought not to be taken as a basis for calculating future operations.

The operating economies proposed by the Department of Public Utilities have not, as yet, been put into effect for the reason that the physical connections between certain of the lines have not been completed; the skip-stop system has been installed on only four lines; downtown traffic is more congested than ever, the new traffic code having just been passed by the City Council; the campaign for the saving of power has been installed on only a few lines; and the thorough co-operation of the employes with the City has not, as yet, been fully effected. However, under practically unchanged conditions the City immediately increased its service so that for the first quarter of its operation it operated 4 146 850 car-miles as against 3 386 311 car-miles for the corresponding quarter of last year, showing that there has been an increase in service of 760 539, or a little more than three quarters of a million car-miles, carrying a total of 33 015 082 passengers as against 28 394 008 total passengers for the corresponding quarter of last year.

The total revenue for the first quarter of this year was \$1 299 039 as against \$1 135 123 for the corresponding quarter of last year, and the total operating expense for the first quarter of this year was \$1 052 728, leaving a profit over operating expenses of \$246 312. From this there has been set aside the sum of \$198 781 to pay the interest on all outstanding obligations. Also, there has been set aside \$20 000 more than has been paid out for accident claims, and approximately a like amount of \$20 000 more than has been paid out for in-

dustrial insurance, leaving a net profit for the first quarter of $6 809.

The wages of trainmen and other employes were increased practically fifty percent. The following schedule of wages paid motormen and conductors under City operation as compared with wages paid by the Puget Sound Traction, Light & Power Company shows the increase that was paid to trainmen beginning April 1, 1919:

	Company Scale	City Scale
First six months	36c	53⅛ c
Second six months	38c	56¼ c
Over one year	40c	59⅜ c

It will be noted that no amount has been set aside for depreciation, for the reason, which this department deems sufficient, that there has been expended during this quarter for maintenance of ways and equipment the sum of $230 540 as against $131 797 during the same period in 1918. Approximately $100 000 more has been spent by the City for extra maintenance of track, overhead system and street cars for this quarter than was spent by the company for the corresponding quarter of last year.

The Traction Company set aside approximately $25 000 per month to take care of depreciation and allowed the property to depreciate. We believe that spending this depreciation fund now on the tracks and equipment (at least until the same are restored to a normal condition) is wiser than allowing the fund to accumulate, because value of the property is appreciating instead of being allowed to depreciate.

We expect to show in the near future, upon the completion of the special work at the Fifteenth Avenue Northwest Bridge and the completion of the elevated railway and the trackage on Avalon Way, and with the complete installation of the skip-stop system, with certain reroutings, and the installation of express service on through lines, a large gain per month over the first quarter—at least enough to take care of the further increases of wages to employes made necessary to meet the increased cost of living. It must be remembered, however, at this time, that the railway is still maintaining the largest franchise obligation, from a financial standpoint, that the private company agreed to maintain, i.e., the care and maintenance of that portion of the street covered by the railway tracks. This, the department feels, is not a proper railway expense under city ownership and management.

The rise in wages and prices of material caused by the war affected all lines of business, but none more pronounced than the street railway business. Nothing is more certain in this field than the fact that the business can no longer bear the charges and burdens that it has borne in the past. This is evidenced by the number of street railway companies that have gone into the hands of receivers throughout this country; by the miles of track that have actually been abandoned and taken up; and by the applications for relief from franchise obligations that have been made almost universally to the appropriate authorities.

It is now quite generally admitted, by everyone who thinks seriously on the subject of urban transportation, that it is impossible to pay out of a five cent fare all the things that have been paid out of it in previous years. Four standard methods have been tried or urged upon the street railways to meet the change in conditions, viz:—

1—Increase in fare.

2—Relief from franchise obligations.

3—Economies in operation.

4—Public ownership.

The fallacy of these methods is that no one of them alone will suffice,—there must be a combination of at least three of them. The fourth method (public ownership) is not, taken alone, sufficient. It must be accompanied by Nos. 2 and 3.

Increase of fare has been tried almost universally and, while an increased fare brings increased revenue, it does not do so in proportion to the increase in fare, showing that a large percentage of the people, under an increased fare, do not use street cars. The short-haul patron walks and the longer-haul patron rides only when necessity compels him to do so. This affects not only the railway but the manufacturer and the business man as well, and is not compatible with the idea of service. The reason for this, is to a large degree psychological. Other commodities have raised in price without a large decrease in their use, why cannot the street railway raise its fare and all the people still ride? The placing of two coins in the fare box, even if one is only a penny, seems much larger than placing the nickel alone, and the purchase of metal tickets, or other emblems, is not satisfactory because it cannot be spent in other ways. If the Government would coin a six-cent piece and a seven-cent piece it would go a long way to destroy the psychological effect of the increase in street car fare.

The relief from all franchise obligations is imperative, and under public ownership and management there can be no just reason advanced why any portion of the nickel fare should be taken to pay other than legitimate railway expenses; in fact, if the City is deemed to owe a duty in the way of transportation, and everyone admits that transportation is a vital element in urban life, then the street car patron should be placed on an equality with patrons of other conveyances. The City, by its local improvement district, builds and paves streets free of charge to the automobile and maintains the street from its general fund. Our position is that the street car rider and the motor car rider should be placed on an exact equality. The jitney rider must pay a fare such that out of it can come wages for the driver, cost and maintenance of car and motive power. The roadway or track for the motor car, either privately-owned or operated as a jitney, is originally built and maintained at no cost to the owner or patron of the motor car or the jitney. The street car rider's fare has to pay the cost of the car and its maintenance, the motive power and operating expenses of the street car, and

must also build and maintain not only its own track but, to a large extent, the track of its competitors in the field of transportation.

No one, who is unselfishly interested in the subject of urban transportation, should be so committed to any particular type or system of transportation that he would want it to continue if it might be supplanted by a better one. If the motor car can render service equal to the electric railway car, at a less cost, the sooner Seattle or any other city is convinced of that fact, and acts upon it, the better. But before any city can choose intelligently between rival systems of transportation it must first place them on an equal competitive basis, removing handicaps and equalizing burdens. From available knowledge, there is no indication that the motor car can fill the place now occupied by the street railways. They can perhaps take the cream of the business away from the street railways and make their operation unprofitable. Where the railway systems are privately owned, the motor car may drive them into bankruptcy. Under city operation, unregulated jitney competition, while it cannot bankrupt the city, can make its street railways unprofitable and result in placing a burden upon the taxpayers that they would not have if the street car and the jitney were placed on an equal basis.

Seattle now has such control over its transportation problem that it can determine the relative merits of electric street railways as compared with motor cars or any other system of transportation that may be proposed. All that it need do is to place them upon an equal footing, so far as can be done, and permit economic laws to operate and the riding public finally make its choice. So far as can be seen at this time, that choice will fall upon electric railway transportation, and there seems to be no question but what street railways are destined to remain the reliable method of transportation in every city.

Decreased Operating Costs with Helical Gears

G. M. Eaton
Engineer in Charge, Railway Dept.,
Westinghouse Electric & Mfg. Company

The question of reduced operating costs has been burned into the minds of operating men for years, and in the present crisis in railway financial affairs, has assumed paramount importance. Reduction in the weight of cars and equipments appeared to be the most obvious saving and has been followed progressively for several years. Some disappointment has been experiencel because the inherent savings in lighter weights have been in a measure offset by maintenance costs that were higher than was anticipated.

The unquestionable fundamental advantage of weight reduction cannot, however, be lightly sacrificed, and the next logical step lies in a searching analysis of the fundamental causes that produce deterioration in railway structures. It is often stated that railway apparatus, on account of the drastic service conditions, must be of the most rugged construction, and experience shows that deterioration and ultimate failure will inevitably follow unless proven practice is observed. But these are glittering generalities and fail to solve the problem.

Why is railway service drastic as compared with other services? A railway vehicle is a moving structure operating in the presence of dirt and moisture. Dirt and moisture are the progenitors of an evil race of troubles, but in the first analysis they affect heavy equipments as seriously as they do the modern light weight equipments. We must, therefore, look farther for the answer to our question.

Why is a moving structure harder to maintain than a similar stationary structure? A moving structure involves dynamic conditions that are absent in a stationary setting. The dynamic forces acting on a railway car become more serious as the structure weights decrease in their proportion to these forces. If the dynamic forces decrease as rapidly as the weight and resisting power of the structure decrease, a comparable rate of deterioration may be justly anticipated. Therefore, the keynote of successful light weight cars and equipment lies in reducing to a minimum the dynamic forces involved. These dynamic forces may be divided into two classes:—

a—Those originating outside the car.
b—Those originating in the car itself.

The former class lies outside of the direct sphere of influence of the manufacturer. The manufacturer has talked and written at great length about how bad track pyramids the cost of maintenance, but in general the results he has achieved are microscopic. He has only recently realized that he could join in a campaign with the superintendent of equipment, or the master mechanic to banish the dynamic forces originating in the car itself.

Varying degrees of track disturbances are at present regarded as fundamental; there being the widest imaginable range of ideas as to what is good enough. In the same way, the dynamic forces inherent in spur gear operation were regarded as unavoidable until Mr. W. E. Moore conceived the idea of departing from the traditional spur gear and secured the assistance of R. D. Nuttall Company in applying on the West Penn Railways, a trial set of helical gears. The installation of these gears is destined to be regarded as one of the great turning points in electric railway practice. The operation was so smooth and free from vibration, (which is only another name for a dynamic condition),

that the R. D. Nuttall Company brought it to the attention of the Westinghouse engineers. The two Companies working together made sufficient further trials to demonstrate the great advantage attendant upon the use of this type of gear, and the Westinghouse Company has recently standardized on helical gears for their small railway motors, since these operate under conditions where the weight reduction campaign is most active.

Vibration will occur in spur gears produced in line with the best modern practice as regards material, machining operation and heat treatment. There has been a considerable advance in the accuracy of cutting spur gears, and there has been a notable advance in the methods of heat-treatment. These advances however,

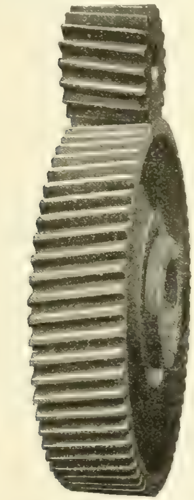


FIG. 1—HELICAL GEAR AND PINION AFTER RUNNING APPROXIMATELY 300 000 CAR MILES

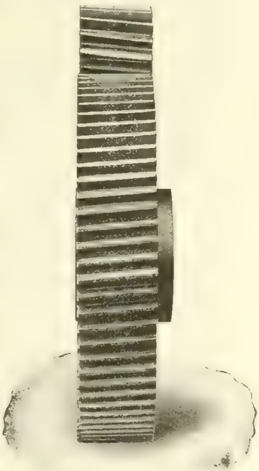


FIG. 2—NEW RAILWAY HELICAL GEARING

were merely detail improvements and failed to reach the fundamental cause of spur gear vibration.

ANALYSIS OF SPUR GEAR PERFORMANCE

In city service, accumulated experience has shown that the most economical pinion usually has from fourteen to sixteen teeth. In such pinions, for a portion of the time that any given tooth is in contact with the gear, the entire load of the motor is carried by that tooth alone. During the remaining portion of its action with the gear, it is assisted in carrying the load by the tooth ahead or the tooth following. A pinion tooth is a beam, fixed at its root and loaded as a cantilever by the motor effort. This load produces tooth deflection, varying as a function of the loading. When a pinion tooth first makes contact with a gear tooth, the distance between this pinion tooth and the pinion tooth leading it in the mesh, is less than the normal pitch by an amount equal to the deflection of the leading tooth. At the same time, the distance between the contacting gear tooth and the gear tooth leading it into the mesh, is greater than the normal pitch by an amount equal to the deflection of the leading gear tooth, that is, the two deflections noted are added together to produce relative displacement of the contacting gear and pinion teeth, bringing them into contact sooner than should occur. Spur tooth contact under load, therefore, is unavoidably accompanied by shock and vibration. With the best tooth-cutting methods, there are slight inaccuracies; furthermore, essential clearances in armature bearings and axle bearings permit slightly varying gear center distances.

These two features of tooth stress and of inherent inaccuracies co-operate to produce shock coincident with tooth contact, with resulting vibration, particularly at the higher speeds.

To this point, the analysis has dealt with new equipments in the best of condition. As soon as a new spur gear equipment is put into service, the sudden fluctuation of tooth load begins as previously described, producing a great variation of tooth pressure. That is, instead of transmitting the average effort at a steady rate, a plotting of the actual tooth pressures with spur gearing would show a succession of peaks and depressions. The peaks tend to squeeze out the lubricant and do actually produce local wear on the tooth, resulting in a departure from the original contour of the tooth. The great advantage of heat treatment of gears lies in the ability of the material to withstand this tendency; but the wear, even with the heat-treated spur gears, will eventually distort the tooth contour, although a much greater length of time is required to produce this result. As departure from the original contour of the tooth increases, the resulting shock and vibration become cumulative: at the same time the armature and axle bearing wear accumulates, permitting greater vibration, and also increasing the severity of tooth shock. A complete cycle of progressive deterioration is thus established.

The cure for this condition lies in producing gearing in which tooth deflection is reduced to a minimum and in which each tooth enters the mesh with the least resistance. This result is realized in helical gearing, that is, gearing where the tooth is no longer parallel to the axis of the gear and where the gear and pinion are each a short section of a screw, having as many threads as there are teeth.

ANALYSIS OF HELICAL GEAR SERVICE

The action of this type of gear is best realized by thinking of it as if it were made up of a number of thin spur gears with the teeth of each successive gear element advanced through a small angle relative to its neighbor. It then becomes clear that only one tooth of one narrow gear enters into contact with the corresponding tooth of the single narrow pinion at any given time. The shock resulting from this entry bears to the whole operation an importance depending directly upon the width of the narrow gear and pinion element. But in helical gearing the width of the element is zero,

therefore, the operation of helical gears is very smooth.

Although the distribution of load over the tooth is much better in helical than in spur gearing, there is still a certain amount of tooth deflection, and it is important to consider the entry of the helical gear tooth into its work. Due to the departure from parallelism to the axis, one end of the helical tooth enters the mesh in advance of the rest of the tooth. As this end picks up its load, it must deflect; but the secret of success in helical gearing lies in this point, that only a small portion of each tooth picks up its load and deflection at any given time, and the resulting shock and vibration, as proved by actual service, exists only in theory and cannot be detected by ordinary methods.

Helical gears transmit practically average motor effort with well-maintained bearings. Therefore, there are no peaks of effort to cause local departure from the original contour of the tooth, and again, helical gears tend to wear evenly over the full tooth length, thus preserving their original tooth form. The absence of shock and vibration decreases bearing wear, reacting advantageously on the gear performance.

GEAR NOISE

The noise accompanying the operation of spur gears in railway service is a direct by-product of shock and vibration. Noise means expense. Since helical gears operate practically without shock and vibration when installed with good bearings and alignment, they offer to the master mechanic an opportunity practically to eliminate gear noise from his cars.

EFFECTS OF GEARS ON OTHER PARTS OF EQUIPMENT

End Thrust—The question naturally arises as to how the end thrust, inherent in helical gears, will be handled. The angle of the gear tooth is so adjusted, that the end thrust is well within the capacity of the oil film on standard armature end thrust collars and on the axle collars. Experience with these gears in service has proven that the amount of wear on the end thrust collars is practically identical with the wear occuring with the spur gear motors. The probable reason for this is that in a spur-geared motor, the armature is subject to only frictional restraint in the direction parallel to its axis. Therefore, when track irregularities cause a sudden movement of the wheeled axle across the rails, this movement causes sudden displacement of the motor frame and armature. The end thrust collars then engage with a shock and there is a tendency to break, or at least thin out the oil film on the end thrust collar. At the same time, the armature, which is rotating, rubs on this reduced oil film and a certain amount of wear results; this wear tending to increase more rapidly as the end play of the armature increases. With helical gears, there is a slight restraining force tending to hold the armature against one of the end thrust collars in a given direction of operation, and against the other end thrust collar in reverse operation. This force, of course, in itself would tend to wear the end thrust collars were it not, as stated previously, kept within the limits of the oil film capacity: but at the same time this force sufficiently reduces the amount of hammering of the armature against the end collars and compensates for any wearing tendency, due to the sustained pressure on the thrust collars.

Experience with herringbone gears, as they are ordinarily installed in heavy industrial service, is that they are incapable of sustaining end thrust; and where this is present, serious wear of the gearing occurs. This is due to the fact that the end thrust with herringbone gears is, of necessity, carried on the gear teeth.

With the helical gears under discussion, however, the tooth angle is such that any end play of the armature is accompanied by a screwing of the pinion tooth past the gear tooth, with only a frictional resistance and a very small direct force component; and experience has proven conclusively that the end play which is permissible with spur gearing, is also permissible with helical gearing as far as the good of the gear itself is concerned.

Commutators—Armature end play has been regarded as a desirable feature, as far as wear of the commutator is concerned, not only in railway motors, but in rotating commutator machines of all classes. Ball-bearing operation of railway motors however, has shown conclusively that, with modern railway motors, it is not necessary to have end play between the brush and the commutator in order to secure proper commutator wear; and it is interesting to note in this connection that there is a very active movement at this time in large stationary apparatus to omit the oscillators, which at one time were regarded as an essential for proper operation.

Armature Bearings—It was thought that reduction of the end play of the armature might affect the armature bearing undesirably, as a slight end play with oil and waste lubrication may be of some assistance in distributing the oil film evenly on the journals. Here, again, no bad effects have been found in service, rather the contrary has been the case, that is, the practical elimination of vibration has produced enough improvement in bearing life to entirely over-shadow any theoretical loss, due to the reduction of the end oscillation of the armature. The same is true of the commutator life, that better commutator life may be expected with helical gears than with spur gears.

Brushholders—Vibration is the worst enemy with which railway motor brushholders have to contend, and the elimination of that portion of the vibration directly traceable to spur gears causes a material increase in the life of all brushholders parts.

Open Circuits—The cause, or causes, to which open circuits are traceable are very obscure and only very extensive operation and a careful analysis of service data will justify any firm conclusion. But the tendencies to date are favorable for a material decrease in the number of open circuits when helical gears are used.

Insulation—Spur gear vibration produces serious results, under aggravated conditions, to the motor insulation and the improvement logically to be expected with helical gear operation is obvious.

Loose Punchings—A great deal of trouble was experienced in the early days with loose punchings, and it has been proven conclusively in a number of cases that spur gear vibration contributed materially in producing this condition, because many of the old motors have been examined where the punchings were tight on the commutator end and progressively looser until they were destructively loose at the pinion end. Comparatively little trouble from this feature occurs in modern motors, but the point is mentioned as illustrating the severity of spur gear vibrations and as calling further attention to the desirability of eliminating these vibrations.

Axle Caps—Spur gear vibration contributes to a very considerable extent to the loosening of the axle caps. The adoption of helical gears can hardly be expected to eliminate this trouble entirely, and axle caps require faithful inspection; but a very noticeable reduction in the amount of loosening is logically to be expected. This means that there will be less trouble with loose axle bearings, and leads to the conclusion that when helical gears are operated, there is a real inducement for keeping the axle bearings in good condition because, with a reasonable amount of maintenance, smooth, quiet gear and car operation can be secured, and where noisy operation does occur with helical gearing, it is a direct proof that the cars have not received the degree of care and attention to which it is entitled.

OPERATING RESULTS WITH HELICAL GEARS

Helical gearing has been in operation on at least eight different electric railways for periods up to three years. The results on the West Penn system, which was the first road to equip trial cars with this type of gearing, are briefly outlined in the following letter:—

R. D. Nuttall Company,
Pittsburgh, Penna.
Dear Sir:—

With regard to the helical tooth gear and pinion we shipped you recently to be exhibited at the A. E. R. A. Convention to be held at Atlantic City this fall, I wish to advise that this gear and pinion were put in use under car No. 203 during February, 1915, and have been in continuous use up to the time they were removed to be sent to you. During that period, this car ran a total of 284 248 miles. I might mention that this car is equipped with magnetic brakes, which means that this gear and pinion have performed almost a double duty as compared with a car that is equipped with air brakes.

During the time that this gear and pinion have been in use, we have carefully observed the end wear on the axle and armature bearings, and as far as we can find there was no more than with the regular spur gear. This is also true of all other helical gears and pinions we have since put in use. In some cases, this wear actually seems to be less.

The motor maintenance with the use of this type of gear and pinion is reduced from 25 to 50 percent. Open-circuited armatures and buck-overs are almost entirely eliminated. As a matter of fact, an old style motor, equipped with this type of gear and pinion, performs almost equally as well, as far as commutation is concerned, as the present-day interpole motor does. The use of this type of gear eliminates all gear noise and vibration, which is the real reason for the good motor performance mentioned above.

The wear of this gear and pinion is about one-third of what takes place in the case of spur tooth gears. In other words, the helical tooth gears are giving from two to three times as much wear as the spur tooth gear.

We have at present 32 gears of this type in use and we expect to use 56 which are now on order, when received, on Wheeling Traction Company's cars.

Yours very truly,
(Signed) DANIEL DURIE,
General Sup't.
West Penn Railways Company.

The length of life and the percentage of maintenance reduction Mr. Durie gives, may or may not be an ultimate average, but his general experience is what must be confidently anticipated, as the rapidly growing application of helical gears becomes more general.

More promise for large savings is offered by helical gears than by any other recent advance in electric railway practice.

Things to Consider in Handling the Public

W. H. BOYCE
Superintendent,
The Beaver Valley Traction Company

EVERY public utility manager who has not been doing a Rip Van Winkle during the past several years, surely is awake to the value of public opinion and is either casting about for ways and means of bettering relations with his public, or is about to be claimed by obsolescence. If for a moment he imagines that results are to be obtained by things he says, rather than by things he does—well the same answer.

The man who is alive to things as they are has had plenty of evidence during the past two years that public opinion does count. If he doubts, to what does he attribute the fact that in a great many cities and towns throughout the United States, railways have been able to secure increases in the rate of fares with little or no opposition, while in other communities all attempts at securing just and much needed increases have met with the most strenuous opposition. There certainly are reasons for this—reasons that cannot be overcome in their entirety by a publicity campaign. Publicity alone is not a cure-all. Publicity here is used in its generally accepted sense, that is, the printed word, and although this method of acquainting the public with the difficulties of operating a street railway system under present day conditions is absolutely necessary, this method alone will not stand the test.

There are many other things to be considered in handling the public. Probably the most difficult, yet one of the first things to accomplish, is for the utility manager to be able to see, know and judge his system as it is appraised by the public.

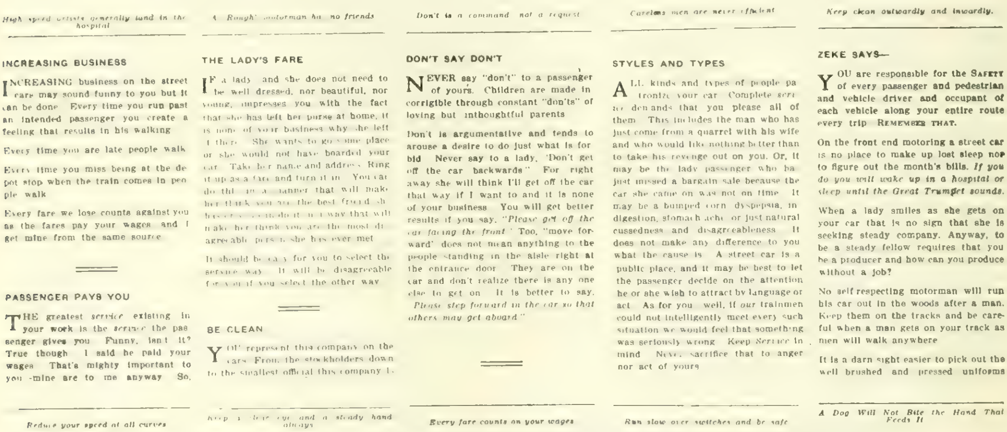
ADVERTISING

The Bell Telephone Company and the Pullman Company started their advertising early. Don't let yourself get into the class with the meat packers. What constitutes effective advertising is largely determined by the kind of a community you serve, and a discussion of this subject would furnish sufficient material for an article in itself. But there is one thing that must not be overlooked. Do not let your public get the impression that the conditions confronting you are exceptional. They might attribute the cause to local management, and your public has and knows that it has a right to expect from you the lowest cost possible under efficient management. Show the conditions in the railway industry throughout the country.

Continuous stereotyped matter is of little substantial benefit in the public utility business except as it maintains friendly relations with local advertising service. When an improvement that will benefit the public is made, do not neglect to give it proper publicity, showing its cause, effect and cost.

Your public should know the competition that you are compelled to meet in the form of the privately owned automobile, and in a measure the telephone, express, parcel post, delivery trucks and wagons, and that in a way you are subsidizing some of these competitors by maintaining many thousand square feet of street paving. You must consider the diversity of the mental characteristics of your customers and frame advertisements and form friendships to cover the whole field for, in this business, although the street car has been termed the poor man's auto, you must reach all classes.

Advertising has been likened to the bird dog—useless unless the hunter is right behind to bag the game as it is uncovered. The street car platform is a wonderful place to make friends. The proper kind of


High speed artists generally land in the hospital

INCREASING BUSINESS

INCREASING business on the street cars may sound funny to you but it can be done. Every time you run past an intended passenger you create a feeling that results in his walking.

Every time you are late people walk.

Every time you miss being at the depot stop when the train comes in people walk.

Every fare we lose counts against you as the fares pay your wages and I get mine from the same source.

PASSENGER PAYS YOU

THE greatest *service* existing in your work is the *service* the passenger gives you. Funny, isn't it? True though. I said he paid your wages. That's mighty important to you—mine are to me anyway. So,

Reduce your speed at all curves

A "Rough" motorman has no friends

THE LADY'S FARE

IF a lady, and she does not need to be well dressed, nor beautiful, nor young, impresses you with the fact that she has left her purse at home, it is none of your business why she left it there. She wants to go some place or she would not have boarded your car. Take her name and address. Ring it up as a fare and turn it in. You can do this in a manner that will make her think you are the best friend she [illegible] that will make her think you are the most disagreeable person she has ever met.

It should be easy for you to select the service way. It will be disagreeable for you if you select the other way.

BE CLEAN

YOU represent this company on the cars. From the stockholders down to the smallest official this company [illegible]

Keep a clear eye and a steady hand always

Don't is a command, not a request

DON'T SAY DON'T

NEVER say "don't" to a passenger of yours. Children are made incorrigible through constant "don'ts" of loving but unthoughtful parents.

Don't is argumentative and tends to arouse a desire to do just what is forbid. Never say to a lady, "Don't get off the car backwards." For right away she will think I'll get off the car that way if I want to and it is none of your business. You will get better results if you say, "*Please get off the car facing the front.*" Too, "move forward" does not mean anything to the people standing in the aisle right at the entrance door. They are on the car and don't realize there is any one else to get on. It is better to say, "*Please step forward in the car so that others may get aboard.*"

Every fare counts on your wages

Careless men are never efficient

STYLES AND TYPES

ALL kinds and types of people patronize your car. Complete service demands that you please all of them. This includes the man who has just come from a quarrel with his wife and who would like nothing better than to take his revenge out on you. Or, it may be the lady passenger who has just missed a bargain sale because the car she came on was not on time. It may be a bumped corn, dyspepsia, indigestion, stomach ache or just natural cussedness and disagreeableness. It does not make any difference to you what the cause is. A street car is a public place, and it may be best to let the passenger decide on the attention he or she wish to attract by language or act. As for you, well, if *our* trainmen could not intelligently meet every such situation we would feel that something was seriously wrong. Keep *Service* in mind. Never sacrifice that to anger nor act of yours.

Run slow over switches and be safe

Keep clean outwardly and inwardly.

ZEKE SAYS—

YOU are responsible for the SAFETY of every passenger and pedestrian and vehicle driver and occupant of each vehicle along your entire route every trip. REMEMBER THAT.

On the front end motoring a street car is no place to make up lost sleep nor to figure out the month's bills. *If you do you will wake up in a hospital or sleep until the Great Trumpet sounds.*

When a lady smiles as she gets on your car that is no sign that she is seeking steady company. Anyway, to be a steady fellow requires that you be a producer and how can you produce without a job?

No self respecting motorman will run his car out in the woods after a man. Keep them on the tracks and be careful when a man gets on your track as men will walk anywhere.

It is a darn sight easier to pick out the well brushed and pressed uniforms

A Dog Will Not Bite the Hand That Feeds It

FIG. 1—SAMPLE PAGES FROM "EMPLOYEE'S SERVICE CODE" PUBLISHED BY THE BEAVER VALLEY TRACTION COMPANY

mediums, and keeps your public in a different frame of mind from that which is in evidence when a utility first starts to advertise or advertises but intermittently, for in these latter cases the public by instinct is suspicious that "some job is about to be pulled", therefore, the continued use of a small advertising space at all times and a larger amount of space as warranted, is advisable.

The old press agent methods are passé. When you have anything to tell your public in the newspapers, put it into a paid-for advertisement that will show for itself that it is a paid-for advertisement. If you have a bad operating condition that for some reason you cannot correct, do not wait for the newspapers to make a story of it. Put the whole truth and your explanation in a paid-for advertisement. It will certainly take out the sting. Cuts attract more attention than reading matter. Circular letters may be used effectively by themselves or in connection with other forms of advertising to accomplish particular results. Your public should be made to realize that the community would be much better off with 10 cent service than without trainmen make many friends for themselves. Why not have them make friends for your company? Start your publicity campaign with your blue uniform men.

NEWSPAPERS

As a rule you will find newspaper men just as fair, if not fairer than railway men, but one must be extremely careful in the manner in which he attempts to "stand in" with the newspapers. Editors and proprietors guard their so-called rights with extreme jealousy, but they will not trouble you a great deal if the public is not against you. Furnish service to newspapers as well as passengers. Have someone designated from whom newspaper men are to secure information. The reporter, cub or veteran, can do more for or against you than any one individual in the community. No matter how much you might dislike his personality or his method of handling news items concerning your system, you will do well to cultivate him.

THE PUBLIC

If a public utility official will trust the public as he trusts an individual friend, it will not take him long to

form a degree of understanding between his corporation and his public that is of tremendous value in times of stress. Whenever one undertakes to convince the public of the absolute necessity of a certain utility to the public without considering and laying due amount of stress on the value of the public and its goodwill to the utility, then there is about as much chance of that individual and his public getting along together as two strange bulldogs.

Never lose sight of the fact that public opinion can make or break any company, particularly if that company is in need of fare increase, or franchise extension or relief from any of the numerous burdens that a public could or would put upon it. Then consider that public opinion is nothing more than the aggregate of individual or personal opinions. A publicity campaign through car cards, advertising programs and newspapers, will not work miracles within a few days or a few months. A judicious combination of deeds and words will be more effective.

One of your tasks is to remove the impression, if it prevails, that you and the public are working for opposite results. You make a sad mistake if you try to prove to your public that it is wrong. Acquaint it with enough of your difficulties so that it will find out for itself that it is wrong. Forget not that the public is to be the judge of your service.

COMPLAINTS

Stop, Look and Think—are you one of those individuals who is too prone to the manufacturing of excuses rather than making an honest attempt to correct conditions, where corrective measures are necessary? Complaints should be treated in the light of indicators that point out the real weaknesses in your service. It is generally a very hard matter to get the public to believe that the proper attention will be given its individual complaints. There are many things one can do to overcome this impression. No matter how irate or unreasonable a complainant is, in person or by letter, he must always be treated with the greatest courtesy. If for any reason, action on a letter complaint cannot be had for a period of several days, so inform your correspondent at once.

Satisfied customers are valuable assets. To satisfy your customers you must have; first, courteous, obliging trainmen; second, clean cars, run on schedule; third, and one of your most valuable assets is to have well-heated cars in winter time.

Many of your patrons have the firmly embedded idea that they are giving your company so many dollars per week, month or year. It is not hard for you to realize that in the tone of some of the written or verbal complaints. This "regular patron" should be shown what you in turn are giving him. In a good many cases it is not a fair exchange at all. You are giving him more than you receive. Make him realize that.

PERSONALITY

Inject personality. John Doe with the individuality of even a Fatima cigarette can certainly get more people to listen to and work for him than can any corporation as a corporation. More good will result in your being generally known as say "Bill Day" than "The General Manager of The Blank Street Railway Co." Fail not to uphold the dignity of your position, but do not feel so big that your public will feel that you think you own all the territory your lines traverse.

Don't make a show of your official position in view of the public, especially if just breaking into new surroundings. Let the general public find out who you are in other ways. Bear in mind that your position as general manager of a public service corporation carries with it an implied duty that even *you* serve the public in many ways. Employ subordinates whom you can entrust with the details of the business, and spend your time in the actual managment of the business and in cultivating your public.

You cannot shove a paper under your patrons door as is done at the Hotels Statler, but you can pat them on the back in other ways. Much can be accomplished through community entertainment. By community entertainment is meant the entertainment you furnish in the form of a dance, or otherwise, to your friends of the community. At these affairs in communities under 75 000 population, forget social caste or barriers. Remember your friends. It can be done.

You do have friends who will believe the facts you give them about the financial condition of your company. Impossible, of course, but suppose you could rate every person in your community a friend. Wouldn't things be easy for you?

Many valuable acquaintances may be formed through affiliation with commercial and social organizations. These acquaintances, if properly fostered, will resolve into friendships that will prove of inestimable value in times of trouble. To make a friend a day, or to confine your friendships or acquaintances to one class, is not enough. A "good mixer" in the railway game must be very democratic. You can not make a friend of every person, and oftimes it is not advisable. A recognized "public crab" is a good man to have against you. His being against you makes you a lot of friends. Be diplomatic and exercise judgment in making friends.

To attempt to carry water on both shoulders will prove disastrous. In public statements, give your public the truth or nothing. Keep your agreements. Play fair. Lay all of your cards on the table, because "you can't fool all the people all the time". The line, "Have a Smile for Everyone You Meet", was written for public utility managers.

Be sincere. If you have been doing any or all of these things, keep on doing them. The constant drip will wear away the stone. Never get discouraged. You cannot win the favorable opinion of the public in one day or in one battle as a general could. You must keep everlastingly at it. Time and the proper attitude will do the rest. You will always find it true that "He profits most who serves best".

Comparison of Low-Speed and High-Speed Interurban Freight Locomotives

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IT IS A MATTER of common knowledge that the majority of the steam roads depend upon freight revenues to earn dividends. Previous to the time when these roads were taken over by the government, there was a lively interest in competitive solicitation of freight business. This has been discontinued under government operation. A few freight roads would gladly abandon their passenger business, if permitted; on the other hand it is certain that the few steam roads deriving the major portion of their revenue from passenger traffic would be unwilling to dispense with their freight business.

Compare this attitude of the steam roads toward the freight business with that of many of the electric roads. Apparently the opposite condition exists, in many places. With steam road freight solicitation abandoned under government operation, there is an excellent opportunity for the electric roads to increase their freight business, as the steam roads are not catering to local or short haul traffic. Many of the electric roads carrying freight are alive to this opportunity, but lack capital, equipment and organization to take on this business. It must, however, be recognized that the character of the freight business which the electric road can handle is widely different from that of the steam road. The steam road is graded and equipped to handle heavy train loads over long distances, while the electric road, because of its profile and equipment is best suited to move smaller trains, act as a feeder to the steam or electrified trunk line and engage in the short haul freight business generally. The electric road engaging in this class of business, as well as in the interchange traffic between steam roads and in general freight haulage, must have proper equipment. The roads which are handling this class of business successfully, and on a large scale, are usually equipped with electric locomotives.

FIG. 1—50 TON, 600 VOLT, FIELD CONTROL, HIGH SPEED FREIGHT LOCOMOTIVE
Used by the International Railway Company, Buffalo, N. Y.

Past experience has shown that much thought can profitably be given to selecting locomotives of suitable speeds as well as hauling capacity, thereby better fitting them to the service and power conditions. The feature of the high current demands of high-speed freight locomotives has been brought to the attention of the railway public at various times, but there are numerous places where the high-speed engine is admirably fitted to do the work, and where ample power is available.

THE LOW-SPEED LOCOMOTIVE

The low-speed electric freight locomotive has a very wide application in the electric railway field. The speed of this type of engine usually ranges from seven to ten miles per hour at the nominal rating, while the free running speed on straight level track is ten to twenty miles per hour with rated load. The low-speed locomotive is best adapted to service where the hauls are short, and sidings and stations relatively frequent, a condition that exists on a large number of railway properties. On a system of this kind, where freight is handled at night at hours when passenger trains are not running, or at least running at infrequent intervals, the location of sidings is of secondary importance, as the freights do not have to clear passenger trains at short intervals, if at all. With day operation considerable time is lost on sidings waiting for passenger trains.

The average electric railway is provided with sufficient substation capacity to operate the passenger service with possibly a small margin for emergency conditions. The addition of freight transportation may require increased substation capacity unless planned judiciously prior to inaugurating the service. Without increasing the substation capacity, it is usually possible to take on a certain amount of freight traffic by providing a low speed locomotive which draws a relatively small amount of power. The heaviest trains can be hauled in the off-peak hours, while considerable of the lighter traffic can be taken care of during the day. As a matter of fact, many companies are handling their freight business during the day, and by careful dispatching are avoiding overloading their stations. This practice permits the substations to be shut down in the latter part of the night.

The low speed engine is well suited to handle

switching work in yards or at stations. It is usually provided with two-speed control. The first or half-speed connection is obtained by connecting two motors in parallel and the two groups in series, while the second or full speed connection is obtained by connecting all motors across the line.

The tractive effort of the low speed engine is high and makes it possible to slip the wheels without excessively overloading the equipment. This is a very desirable feature, tending to prevent the transportation department and crews from loading the engine beyond its capacity. The addition of the field control feature reduces the losses in the grid resistors and also enables high tractive efforts to be obtained with reduced current. It provides four economical running speeds—two in series and two in parallel.

THE HIGH SPEED LOCOMOTIVE

The average trainman and operator desires ample speed, for the reason that there is a certain fascination and pride in operating an engine that can go through on passenger schedule. It is well to study the characteristics of an engine of this type to determine its

FIG. 2 50 TON, 600 VOLT, FIELD CONTROL, LOW-SPEED FREIGHT LOCOMOTIVE
Used by the Monongahela Valley Traction Co., Clarksburg, W. Va.

applicability to the service and its effect on substation capacity. The speed of the average high-speed engine ranges from thirteen to sixteen miles per hour at the nominal rating. On level tangent track, hauling rated load, the free running or balancing speed ranges from fifteen to forty miles per hour.

In freight service an engine of this type is regarded as a high speed locomotive, whereas for interurban passenger service, it would be considered medium speed. The high speed engine is adapted to interurban roads which have long hauls with infrequent stops, such as exist on a number of the roads in the central states. On many of these roads the freight is handled at night and the substations have adequate capacity to furnish the necessary power. It is necessary to operate the freight trains during the day on some lines and with this type of engine such service can be performed without serious interference from or with the passenger traffic, provided the power supply and distribution systems are adequate.

The length of time the crews are on the road must also be considered, not only at present, but for the future, as the old order of excessively long hours is fast passing. This means that runs must be completed in a relatively short time and the motive power must have sufficient speed to avoid being held frequently at sidings for passenger trains to clear. Much time is lost in this way.

In electric freight service, the road engine must do switching work at way stations, yards and interchange points. For this work with a high-speed engine, three speeds are better adapted than two speeds. The three speed combinations on a four motor, 600 volt locomotive are:—quarter speed, half speed and full speed. Quarter speed is obtained by placing all motors in series across the line, while half and full speeds are obtained as described for the low speed locomotive. For 1200 volt or 1500 volt locomotives this three speed combination cannot be provided with four motors per locomotive unless each motor is designed for full line voltage. As now built, these locomotives are equipped with 600 volt or 750 volt motors, insulated for full line voltage. Two motors are connected permanently in series and the groups connected in series or parallel to obtain half speed or full speed respectively. To obtain quarter speed, half speed and full speed at least eight motors are required for each locomotive. A six-motor locomotive will provide one-third speed, two-thirds speed and full speed. The motor equipment on this type of engine also provides high tractive effort which makes it possible to slip the wheels without seriously overloading the equipment, thus tending to prevent abuse.

The addition of field control to a two-speed engine provides four running speeds, with no resistance in series with the motors and which therefore are economical running notches. The three-speed field-control locomotive provides six economical running notches. The field control feature reduces the rheostatic losses below those of the non-field control locomotive, and makes it possible to do the same work with reduced currents in the main circuits when employing the full field connection.

MOTOR EQUIPMENT

The standard motor equipment for the low speed 50-ton engine usually consists of four 100 horse-power, 600 volt field control motors with maximum reduction gearing, arranged for 33 to 36 inch wheels, while that for the high speed engine usually consists of four 160 to 200 horse-power, 600 volt field control motors with maximum reduction gearing and 36 inch wheels. For the comparison here given the high speed engine has a motor with double the hour rating of that used for the low speed engine. The total capacity of the motor equipment on the low-speed engine is 400 horse-power, while that for the high-speed engine is 800 horse-power. The low-speed engine will, at the nominal rating of the motors, have a speed of approximately 8.8 miles per hour at 500 volts, while the high-speed engine will have a speed of 14.1 miles per hour at the nominal rating, or 60 percent higher speed than the low speed engine. The low-speed locomotive will have a tractive effort of 14 000 lbs. at the nominal rating, while the high-speed locomotive will have a tractive effort of 17 400 lbs. or

24 percent higher than the low-speed locomotive. All ratings and speeds are based on short field, maximum reduction gearing and 36 inch wheels.

CONTROL EQUIPMENT

The control is usually arranged to permit multiple operation of locomotives, if desired. The electro-pneumatic type mounted in the equipment compartment in the center of the locomotive cab is preferable. All parts are accessible and easily inspected. A large number of notches is provided on the master controller, and proper grouping of motors and gradation of resistance in the main circuits, insures a nearly constant drawbar pull for starting a train smoothly. The proper arrangement of control is very important in keeping wheel slippage at a minimum when starting heavy trains on grades.

COMPARISON OF CHARACTERISTICS

Fig. 3 shows the relative current demand per ton trailing load for low and high-speed locomotives, and also for the purpose of enabling the operator to determine approximately the current demand at maximum trailing load, including locomotive, it is only necessary to multiply the trailing load in tons by the amperes-per-ton for the percent grade to be ascended. The full field connection produces the same tractive effort at the wheel tread as the short field, but with reduced current and speed. This feature is useful in ascending grades at minimum current per locomotive, starting heavy loads with reduced grid resistance losses, and obtaining best commutating conditions for the motors.

In applying this curve to a 1200 volt engine, the amperes-per-ton should be taken at one-half of the values shown on the curve, hence the amperes per locomotive or train are reduced 50 percent by the high line voltage. Two motors are connected permanently in series and the two groups thus connected are paralleled across the line for full-speed. For half-speed, the two groups of motors are connected in series. The speed of the 1200 volt engine is the same as that of the 600 volt engine.

Fig. 4 shows the maximum trailing loads which can be hauled up the various grades by either a low

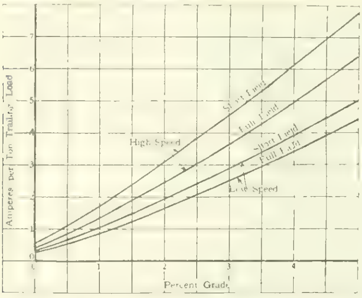
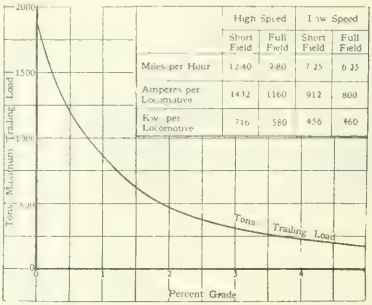


FIG. 3 COMPARISON OF CURRENT PER TON TRAILING LOAD REQUIRED ON VARIOUS GRADES

For low and high-speed, 50 ton, 600 volt, direct-current locomotives, based on maximum load, at 25 percent nominal running adhesion.



	High Speed		Low Speed	
	Short Field	Full Field	Short Field	Full Field
Miles per Hour	12.40	9.80	7.25	6.25
Amperes per Locomotive	1412	1160	912	800
Kw per Locomotive	716	580	456	460

FIG. 4 MAXIMUM HAULING CAPACITY OF LOW-SPEED AND HIGH-SPEED 50 TON LOCOMOTIVES ON VARIOUS GRADES

The table compares the speed, current and kilowatts per locomotive at 500 volts, and maximum capacity.

loads for a 50 ton engine when grades and trailing loads are known. Comparing the amperes per ton trailing, with motors connected to the line for full speed on short field, ascending a two percent grade, it will be observed that the current demand is 1.91 amperes per ton for the low speed engine, while for the high speed engine it is 3.05 amperes, or 60 percent greater. Therefore, the current per train is 60 percent greater. On a five percent grade, the high speed engine will require 56 percent more current than the low speed engine. On full field, these percentages are 49 percent and 45 percent respectively. Running the high-speed engine on full field connection on grades, instead of on normal or short field, reduces the current per ton or per train approximately 18 percent on maximum grades. Running on full field connection with the low-speed locomotives reduces the current approximately 13 percent under that of the short field connection.

To determine the current demand per train with or a high speed, 50 ton, 600 volt engine at 25 percent nominal running adhesion. These loads can be started on the grade shown, by using sand to obtain sufficient adhesion, excepting possibly during very severe weather conditions, when the train resistance is raised by low temperatures. The values of trailing load shown by the curve are permissible under average conditions for grades not exceeding one-half mile in length.

Service conditions and profile have a very important influence on motor temperatures and must be carefully considered on any specific proposition to permit determining the proper trailing loads to be safely hauled. The motor equipments are suitable for the trailing loads shown, only so long as maximum reduction gearing is used. Gearing of less reduction, which gives a faster train speed for either the low speed or the high speed engine, necessitates reducing the trailing loads, and renders the motors less capable of slipping the wheels at maximum adhesion obtainable. It is

necessary, in protecting the locomotive from overloads on grades, to apply a motor equipment which will slip the wheels under best rail conditions.

The table shown in connection with this curve gives the speed, current and kilowatts per locomotive, exclusive of energy for auxiliaries, when hauling these trailing loads. This tabulation was made up for 600 volt engines, and with the assumption that the average voltage would be 500 volts when operating on grades. The values of current, speed and kilowatt demand remain constant when the trailing loads are based upon a given adhesion. The current for the high-speed engine on short field is 57 percent greater than for the low speed engine, while on the full field it is 45 percent greater. The speed in miles per hour for the high-speed engine is 71 percent greater on short field than for the low speed engine, and 57 percent greater on full field. When ascending a grade at half speed, the current and kilowatt demand per locomotive will be reduced 50 percent.

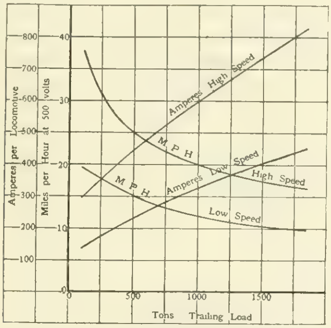


FIG. 5—COMPARISON OF BALANCING SPEEDS AND RESULTING CURRENT PER LOCOMOTIVE AT 500 VOLTS

With various trailing loads, on straight level track for 50 ton, low-speed and high-speed locomotives.

With 1200 volt engines equipped with four motors, the current per locomotive is one-half that for 600 volt four motor locomotives, but the speed in miles per hour is the same with the same motor equipment. The demand in kilowatts is the same for either voltage engine of the same speed.

Fig. 5 shows the balancing or free running speeds at 500 volts with various trailing loads on level tangent track for the two types of engines under consideration. The currents per locomotive resulting are also shown. Referring to Fig. 4, the maximum trailing load which can be handled on a two percent grade, is 480 tons. Then referring to Fig. 5, the speed on the level with this trailing load is 15 miles per hour, while that with the high-speed engine is 25 miles per hour, or 67 percent greater. The current per locomotive at this load is 230 amperes or 115 kilowatts for the low speed engine, and 440 amperes or 220 kilowatts for the high speed engine.

With practically level track between substations, the average voltage will frequently exceed 500 with proper feeder capacity, while on grades, it will usually be less than 500 volts with heavy trains, unless in the vicinity of a substation.

TIME OF RUNS

The character of service to be performed has a very large bearing on the locomotive speed required. Observations have shown that the length of runs between stops varies from 2.5 to 10 miles. On the shorter runs, the time saving is small with a high speed engine as compared with a low speed engine; however, on the longer runs, the high speed engine will give considerable saving in time. To obtain an approximate idea of the time required by the two classes of engines to make a given run, assume that a 600 ton trailing load is to be hauled over a 40 mile line, (80 miles per round trip excluding switching mileage), with stops every four miles, to pick up and set off freight. Also assume length of stops at 15 minutes each, average. The total duration of stop time would be five hours for either engine. The average speed of the low-speed engine would be approximately 11 miles per hour on virtually level track, while that for the high-speed engine would be approximately 18 miles per hour. The low-speed engine would require approximately 7¼ hours running time, while the high speed engine would require 4½ hours, or a difference in running time of 2¾ hours. The switching time would be the same in either case. With crew costs at $2.25 per hour, the labor difference amounts to $6.20 per round trip.

The crew of the low-speed engine would have a 12¼ hour day, while that of the high speed engine would have a 9½ hour day, so that it will be seen that under the conditions assumed, the 9½ hour day will be about as long as can be expected for future work. This indicates that the high-speed locomotive is preferable in this case.

ENERGY

The energy in watt-hours per ton-mile required to haul a train of a given weight, over a road of the same profile, is somewhat less for the low-speed engine than for the high-speed engine. Assume that on a road having three percent maximum grades, the length of the average run is four miles, and the weight of the maximum train which can be hauled over this grade by either engine is 310 tons trailing. The energy consumption, including auxiliaries, would be approximately 48 watthours per-ton mile for the low-speed engine and 52 watthours per ton-mile or eight percent more for the high-speed engine. On an eighty mile trip, including the usual amount of switching, the energy required by the fast engine would be approximately 130 kilowatt-hours more than that required for the low-speed engine. With energy costing three cents per kilowatt-hour at the locomotive, the difference in energy cost amounts to $3.90 per trip in favor of the low-speed engine. On runs of shorter length, the energy economies become increasingly favorable to the low-speed engine on account of the more frequent accelerations, lower train resistance and less energy dissipated in heat-

ing brake shoes and wheels when braking from the lower speed. With increasing distance between stops, the advantage of the low-speed engine in energy economy decreases.

In switching service, a two-speed low-speed engine has a distinct advantage over the two-speed high-speed engine. However, if the high speed engine is arranged for three speeds, as explained previously, it will perform with equal economy in switching service.

CONCLUSIONS

It is apparent from the comparison of the two types of locomotives considered, that adequate energy supply and the service to be performed are the two important factors which influence the selection of a locomotive of proper speed characteristics and hauling capacity. The overall economies are determined largely by the character of service to be performed and the power supply available. A fast engine may economize in time on the road but lose this advantage by making it necessary to provide additional power equipment and feeder capacity. The low-speed engine may perform the service without additional power equipment but interferes with passenger traffic in day operation.

Either type of engine will handle freight with low operating expense and with maximum reliability. Neither the steam locomotive nor the motor truck can successfully compete with the electric locomotive in its field of operation. The electric locomotive is the most dependable unit of motive power in existence.

The electric roads should plan for the future. The present acute situation cannot last for an extended period of time. Better days are ahead. The freight business is becoming increasingly important as a revenue producer. The equipment should be selected to meet, not only present conditions, but also probable future conditions insofar as they can be predicted. In certain sections, the number of stations on a given line will in the future be increased, which means denser traffic. On other systems, the number of stations or loading and delivering points will remain practically unchanged, but the lines will be extended so that longer trips will be made. Energy conditions will change. The supply will become more adequate. In view of the increasing freight business which is sure to result from closer co-operation between steam and electric systems, future extensions and operating plans should be undertaken with full recognition of these facts.

Preventing the Breakage of Armature Leads on Railway Motors

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OPEN circuits due to the breakage of armature coil leads have been a constant source of trouble since the first electrical rotating apparatus was built. However, of all the various classes of electrical machines, this trouble has been most prevalent on railway motors. This failure is caused by the continual bending of the leads at a given point, which ultimately results in crystallization and failure. A careful examination of the broken ends will often disclose the progressive stages of the breaking and leads may be found operating satisfactorily, though more than half broken. The same class of break may be obtained by subjecting a piece of a lead to a great number of small bends. This break nearly always occurs close up to the commutator and is usually just at the edge of the neck.

The fundamental cause of the bending is due to the vibration to which railway motors are subjected, which is much more severe than that encountered by almost any other class of electrical equipment. Some idea of the amount of this vibration may be gotten by standing on the motor through the opening in the car floor while it is operating in normal service. The cause of the vibration is quite different with different types of motors operating under a wide range of conditions. Hence, the specific vibration which is causing the broken leads in a given case is often very hard to identify or overcome. This has lead to the conclusion that there is something very mysterious about the problem.

The bending of the leads and ultimately breakage may be caused by:—

1—Movement of the commutator with respect to the core.

2—Movement of the individual lead with respect to the other leads and end winding.

3—A movement of the total end winding with respect to both the commutator and the core.

The relative importance of these three classes of movement varies with different motors and with different classes of service. An example of the first type of movement is easily seen where motors are operating with loose cores or loose commutators, but examples of the other types are very hard to identify. However, in some cases a careful examination of the coils and insulation between coils will reveal distinct signs of movement.

The forces acting to cause this movement may be divided into two general classes;—first, those external to the armature, and second, those within the armature itself. The external causes are those due to:—

1—Gears and pinions.
2—Bad track.
3—Flat wheels.
4—Too rigid supporting of motor nose.
5—Badly worn axle and armature bearings.
6—Any external influence which may tend to produce vibration or shock to the parts of the motor.

The internal causes are as follows:—

1—The reversal of the magnetic forces acting on the lead as the current reverses when commutated.
2—The change in centrifugal forces acting as the armature speed changes.
3—Forces due to rapid accelerating and decelerating.
4—Core loose on the shaft.
5—Commutator loose on its support.
6—Too flexible a support between the commutator and core.
7—The forces due to the difference in expansion between the copper and the other parts of the motor, caused by changes in temperature.
8—Armatures out of running balance.

The remedy for broken leads may be applied along two general lines. First, reduce as far as possible all vibration; second, make the armature leads and all other parts so that they can safely withstand the maximum amount of vibration. A study of any individual case of trouble will nearly always show where great improvements can be made along both of these lines.

REDUCING VIBRATION

Before making changes to reduce the vibration which is causing the trouble, it would be logical to identify the particular vibration responsible, but this is in most cases impossible and hence the best way is to reduce all vibration to a mimimum by proper maintenance of track and equipment. This, of course, will have a very beneficial effect on the life of all parts of the motor, besides helping the broken lead situation.

Nearly all external causes of vibration can be limited to reasonable amounts by proper maintenance and operation. Badly worn gears and pinions cause excessive vibration and should be discarded. It is often not realized how much damage is done to all parts of the motor by operating with badly worn axle and armature bearings, due to the very bad vibration caused by the spread of the gear centers. This also causes very rapid wear of the gears and pinions, all of which tends to increase the lead breakage.

A track with loose joints, bad crossovers or broken rails is also a very prevalent cause of broken leads. In this connection, it should be noted that a track laid on a very rigid foundation is worse than one laid on a more flexible support, even though the latter may appear worse to the eye. The operation of a car over the latter track may be very bad, but the effect on the motor is less injurious since the motor is affected mostly by the high period vibration caused by the rigid track. Flat wheels will, of course, have the same effect as bad track, and should not be tolerated. Corrugated track is another cause of serious vibration.

Even with the very best maintenance, ordinary spur gears are one of the worst causes of vibration. Hence, helical gears, referred to elsewhere in this issue, will be very helpful in reducing the vibration to a minimum and overcoming broken lead troubles.

The first four items listed under "external causes of movement" can be reduced by not subjecting the motor to excessive overloads, temperatures, or accelerating and braking rates. However, these forces are probably small compared to the others.

CHANGING THE LEADS SO THAT THEY CAN BETTER WITHSTAND VIBRATION

One of the easiest ways to increase the life of armature leads is to make them of some metal better adapted to withstand vibration than copper, which is, of course, used on account of its better electrical characteristics.

The relative life of various metals under vibration can easily be found by testing in an Upton-Lewis toughness testing machine which is arranged to bend the test piece back and forth through any given angle, while at the same time a record is made of the stress produced in the sample and the number of bends produced before failure occurs. Numerous tests have been made by soldering strips of various materials into holders similar to the standard commutator bar construction, and then subjecting them to backward and forward movements. These tests show that phosphor bronze will withstand 25 to 35 times the number of bends that can be withstood by commercial copper. This means that if equal stresses occurred in leads made of phosphor bronze and copper an armature wound

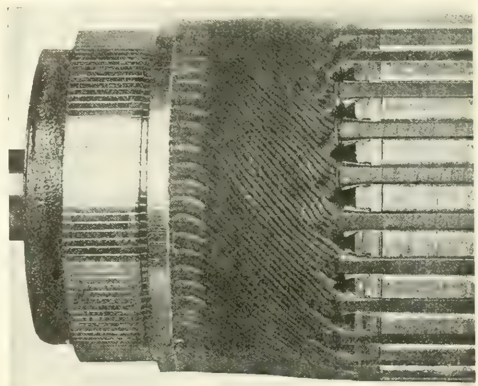

FIG. 1—ARRANGEMENT OF LEADS TO MINIMIZE BREAKAGE

with phosphor bronze leads would have 25 or more times the life. This alone would be sufficient to entirely eliminate this class of failures for, in most cases, over one year is necessary to produce failure in copper leads and hence with phosphor bronze a life of 25 years or over could be expected. However phosphor bronze or any other material tougher than copper is unsuited for armature leads on account of high resistance to the flow of electric current.

If this type of failure were occurring on some purely mechanical part of the motor, a considerable gain in strength could probably be made by changing the shape of the part. But here the designer is handicapped since the lead has a limited space in which to lie. If it were not for these conditions, the problem of lengthening the life of armature leads would be a simple one. However, since copper must be used for the armature conductors for electrical reasons, and the available space can be changed only slightly, the problems must

be attacked with this in view and the necessary modifications made in order to get a long life with copper, and in the space available.

After having reduced the vibration to a minimum, further action must be along the following two lines:—

1—Reduce the possible movement or bending of the lead.

2—Strengthen the lead so that it can withstand some amount of vibration.

In order to reduce all possible movement of the lead, the design of the core and commutator, and the means of holding them in alignment must be very rugged. The coil and leads must be shaped so that they mutually support each other. The leads should be very carefully laid in place so that relative movement between adjacent leads is practically impossible.

An ideal arrangement for the leads of a wire-wound armature is shown in Fig. 1. They are evenly spaced and so placed as to mutually support one another. On some of the older types of motors, it may be impossible to get as good an arrangement as this, but every effort should be made to support the leads so that they are restrained from vibrating. Dipping the armature in varnish and then baking* is also advantageous as it cements the leads together and helps to prevent the movement of the individual leads. Where it is desired to be unusually safe regarding the cementing together of the leads, shellac may be applied before the armature is dipped in varnish.

Care should be used to locate the bands properly over the leads. In general, the bands should be placed so that bending of the leads will not be concentrated at one point should movement of the whole end winding occur and, at the same time, they should tend to prevent the movement of the individual leads. This is usually accomplished by distributing the banding well over the surface of the lead but it should not be brought closer than three-fourth inch from the commutator neck. Two bands with some space between are better than a single band. Temporary bands should be used to pull the leads into their final position while the armature is hot. The permanent bands should not be applied until after the armature has cooled. This tends to make the leads and end winding a compact mass and prevents movement of the leads.

In one instance a bad case of broken top leads was helped by putting a band on the front end winding before the top leads were laid down. This apparently relieved the strain on the outer band to such an extent that the movement of the top leads was reduced sufficiently to greatly increase their life.

STRENGTHENING THE LEADS TO WITHSTAND VIBRATION

One of the first fundamental principles is so to shape the lead as to prevent the concentration of bending at any one point. This means that the number of bends should be limited and made on as large a radius as possible. The bends on the leads in Fig. 1 are on a large radius and well removed from the commutator neck, so that the lead enters the commutator slot without being under any initial strain or likelihood of concentrating the bending at the neck due to a movement of the entire end winding.

Great care should be used in making the coils and in winding the armature to prevent nicking or scratching the lead. A nick or scratch may concentrate the bending and soon cause failure. And for the same reason, all sharp edges of the commutator which come in contact with the lead should be rounded. Only well rounded drifts should be used, or better still, use no drifts at all.

Some experiments have been made with a flexible connection between the armature coil lead and the commutator, but in many cases this scheme has not overcome the trouble. It is, of course, very difficult to make and insulate the connection and the results do not justify the additional expense.

Soldering of the leads to the commutator has been blamed for the breakage and in order to eliminate this possibility several experiments have been made by drifting the lead into the neck without soldering. The results in a few cases have been very satisfactory but the number of cases has been so few that the scheme must still be considered in the experimental stage.

Surrounding the copper lead with a sleeve of some material better able to resist vibration has proven quite satisfactory. The sleeve surrounds the lead in the commutator neck and should extend at least one half inch from the neck. This prevents concentration of the bending of the lead at the edge of the commutator. Due also the fact that the sleeve stiffens the lead, less movement can occur. Phosphor bronze is the most logical material to use for this sleeve as it combines toughness with fairly low resistance to the flow of current. While this method of increasing the strength of the lead has given excellent results its application is limited to a design suited to this construction.

Broken leads may be due to many different causes and an extensive investigation and many experiments may be required before the trouble can be located and suitable corrections applied. The period of experimenting may take considerable time since it is necessary to try out the new schemes in service and, of course, this requires sufficient time to judge the life before a conclusion may be drawn.

SUMMARY

To overcome trouble with broken leads

1—Reduce the vibration as much as possible by:—

- a—Discarding badly worn gears and pinions.
- b—Repairing track having broken joints or bad crossovers which cause severe jolts to the motor
- c—Eliminating flat wheels.
- d—Supporting the motor nose as flexibly as possible.
- e—Discarding badly worn axle and armature bearings.
- f—Giving each motor a running test at high speed after being repaired to see that they are not out of balance.

*See Railway Operating Data on "Dipping and Baking Railway Motors" in the JOURNAL for April, 1918, p. 137. Also article on "War Time Dipping and Baking Outfits" in the JOURNAL for Oct., 1918, p. 400.

2—Increase the resistance of the armature leads so that they can resist vibration by—

a—Reducing the possible movement of the leads as follows:—

1—Eliminate all cases of loose cores and commutators.

2—Locate the leads so that they mutually support each other.

3—Hot band the armature.

4—Dip and bake in varnish or treat with some other material to cement the leads thoroughly in place.

5—Locate the bands so as to give the whole end winding and leads a distributed support.

6—Reband the armature after it has been in service and the insulation dried out, in order to take up any looseness which may have developed.

b—Strengthening the lead to withstand vibration as follows:—

1—Eliminate all possible bends.

2—Make all bends on as large a radius as possible.

3—Do not nick or scratch the leads.

4—Remove sharp edges of the commutator slot.

5—Surround the copper lead with a thin phosphor bronze sleeve (where the construction permits).

Railway Motor Bearings

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Westinghouse Electric & Mfg. Company

A VITAL factor in the life and general utility of a railway motor is good dependable bearings. This statement will be confirmed by the average operating man who has made a careful study of the relative importance of the various details that enter into the make-up of a railway motor. As a result of experience, his interest naturally centers around the bearings, and to further focus his attention on this important subject, the method of manufacturing a bearing in all its details will be outlined and the operations illustrated.

The logical sequence of the various operations required in the production of an armature bearing having a solid bronze shell with a thin lining of babbitt, such as used on modern railway motors, is as follows:—

1—Cast shell
2—Bore and face for babbitt
3—Chip for oil grooves
4—Tin and babbitt
5—Rough turn
6—Burn out windows
7—Broach
8—Chamfer windows
9—Finish turn
10—Profile keyway
11—Chip oil grooves and finish
12—Final inspection

The development of a bearing from the raw material through the various stages of operation to the finished products is shown in Fig. 1. The bronze castings are made from a split metal pattern designed to mould two bearing shells. This is placed in a metal flask in which the sand is packed and rammed by an air-operated moulding machine. The bronze is melted in an oil-heated Swartz furnace and then poured as shown in Fig. 2. When cool, the castings are shaken from the sand and cleaned by tumbling or sand blast

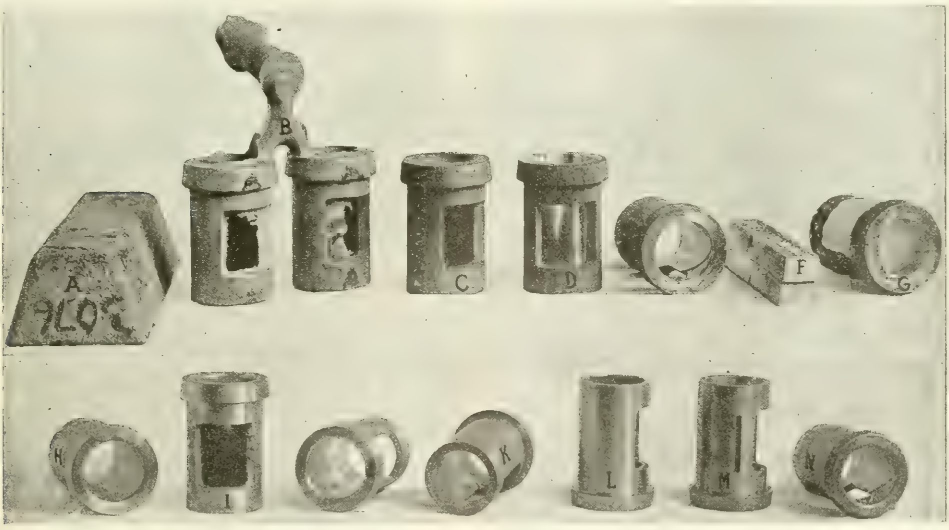

FIG. 1—A RAILWAY MOTOR BEARING IN VARIOUS STAGES OF PRODUCTION

A—Ingot of bronze alloy.
B—Casting as removed from sand.
C—Casting as delivered to bearing department.
D—Bored and faced.
E—Chipped for oil grooves.
F—Ingots of babbitt metal.
G—Babbitted shell.
H—Rough turned.
I—Babbitt burned out at window.
J—Broached.
K—Window chamfered.
L—Finish turned.
M—Key way profiled.
N—Oil grooves chipped in babbitt.

ing, after which the "sprue" or gate is cut off by a high-speed band saw.

After careful inspection in the foundry, the shells are sent to the bearing department, Fig. 3, where they are placed in the universal chuck of a turrett lathe fitted with special boring bars, where the boring and facing of the casting is done, as shown in Fig. 4, without removing the shell from the chuck, which insures accuracy of these operations. Another workman, by means of an air-operated chisel chips the oil grooves in the casting, as shown in Fig. 5.

FIG. 2—REVOLVING CIRCULAR MOULDING AND CASTING TABLE

FIG. 3—GENERAL VIEW OF BEARING DEPARTMENT

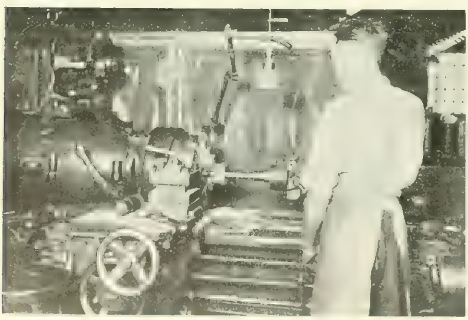

FIG. 4—BORING AND FACING THE BEARING SHELL

The shells are then carefully tinned and placed in a babbitting fixture, Fig. 6, and lined with a good grade of hard babbitt metal poured at a temperature of from 460 to 470 degrees C., which has been found experimentally to be the correct pouring temperature to insure dependable bearings.* The temperature of the babbitt metal is never allowed to get above 470 degrees C. and, while pouring, is kept between 460 and 470 degrees C., by means of an automatic temperature controlling device fitted with a recording pyrometer, as shown in Fig. 7.

FIG. 5—CHIPPING THE BEARING SHELL FOR THE OIL GROOVES

FIG. 6—BABBITTING THE BEARING SHELL

FIG. 7—BABBITTING POTS
Fitted with automatic temperature control and indicating pyrometers.

After babbitting, the bearings are placed on a special expansion chuck on an engine lathe and rough

*For more detailed information regarding the babbitting of railway motor bearings, see "Railway Operating Data" in the JOURNAL for Oct. 1916

turned, Fig. 8, which insures the outside of the bearings being concentric with the babbitt lining. The excess babbitt in the bearing window which is filled in to make a more accurate and uniform job of pouring is then wiped out by means of a bar of iron heated to a red heat, as shown in Fig. 9. In the case of bearings with a

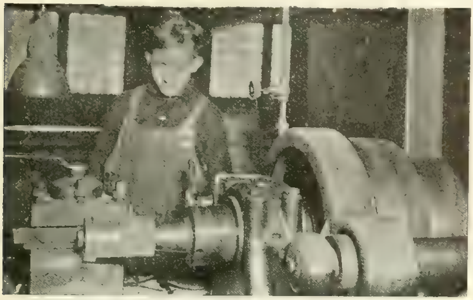

FIG. 8—ROUGH TURNING THE BABBITTED SHELL

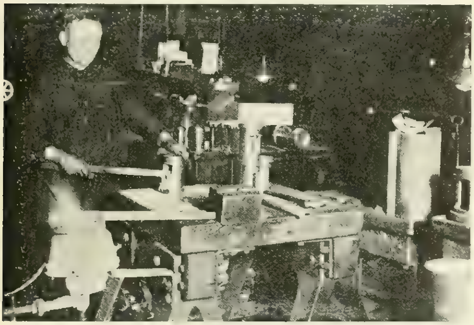

FIG. 9—BURNING THE BABBITT FROM THE BEARING WINDOW

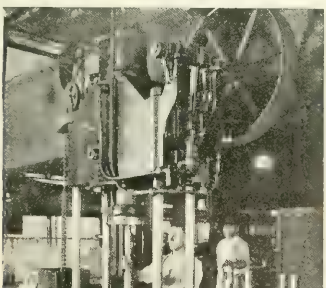

FIG. 10—BROACHING THE BEARING TO FINAL SIZE IN A HYDRAULIC PRESS

heavier lining of babbitt, the windows are cast open, and only the excess babbitt at the edges must be removed.

To broach the babbitt lining, the bearing shell is

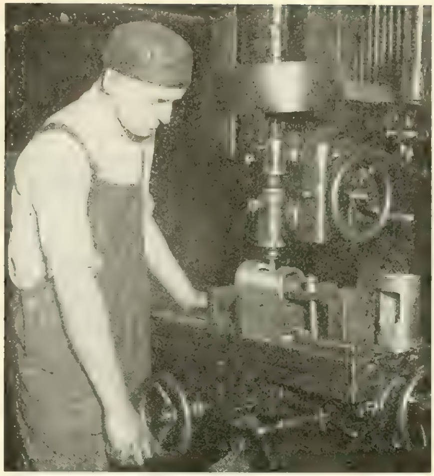

FIG. 11—CHAMFERING THE WINDOW

FIG. 12—FINISH TURNING THE BEARING SHELL

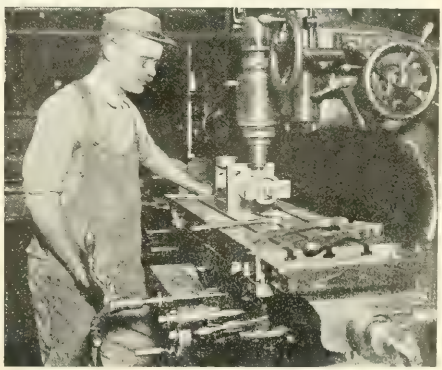

FIG. 13—PROFILING THE KEY WAY
With an end miller in a vertical milling machine

placed in a massive clamp to prevent expansion of the shell. A long hardened steel broach having eleven cutting edges ground without clearance, and each successive edge 0.002 in. larger, is forced through the babbitted bearing by means of hydraulic pressure. This operation, Fig. 10, produces a compact homogeneous smooth bearing surface, which will give long life and the least possible wear, when properly lubricated. Bearings of this size are broached to the journal size plus 0.006 to 0.008 in.

FIG. 14—CHIPPING THE OIL GROOVES IN THE BABBITT

The sides of the windows are then chamfered, after being secured in a special fixture on the base plate of a vertical milling machine. This chamfer, Fig. 11, permits the oil, which is carried up to the journal from the oil well by the capillary action of the waste, to enter readily into the bearing surface of the journal. The bearing is then placed in a special expansion chuck on an engine lathe, and the outside of shell is given its final finishing cut, which is concentric with the broached inner surface Fig. 12. The keyway is cut in the bearing shell by means of an end profile cutter, Fig. 13, after which the oil grooves are cut in the babbitt and the bearing is given the final finish as shown in Fig. 14.

The finished bearings are then turned over to the inspection department, where each bearing is carefully inspected for flaws and defects, and the bore checked by means of a standard plug gauge, to insure the proper fit on the journal. The outside of the shell is measured by means of a micrometer, Fig. 15, to guarantee the correct press fit of the bearing into the housing. If the bearings meet the rigid inspection requirements, they are passed.

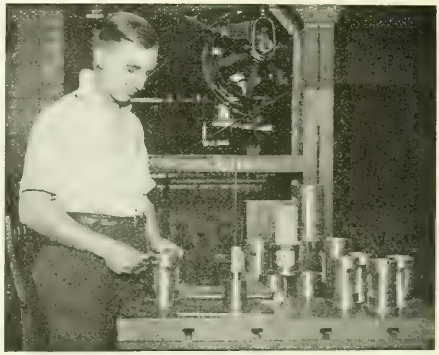

FIG. 15—FINAL INSPECTION OF THE FINISHED BEARING

BEARINGS WITH AN ENVIABLE RECORD

To demonstrate that bearings made by the above methods are dependable and will stand up in service, the history of several pairs of bearings taken from service for an inspection is given in Figs. 16, 17 and 18. All of these bearings were giving satisfactory service when removed for inspection.

FIG. 16—BRONZE SHELL, BABBITT LINED BEARING TAKEN FROM A DOUBLE MOTOR EQUIPMENT WITH MAXIMUM TRACTION TRUCKS FOR CITY SERVICE

Weight of car, 34 300 pounds. Gear ratio 16:73, 33 inch wheels. Total mileage—290 000. Equivalent to 11.6 times around the world. Revolutions of the armature 808 632 000. Maximum pinion end bearing wear 0.062 inch. Maximum commutator end bearing wear 0.006 inch. Actual time in service—7 years.

FIG. 17—BRONZE SHELL, BABBITT LINED BEARING, TAKEN FROM HIGH-SPEED, INTERURBAN LIMITED SERVICE

Weight of car, 76 600 pounds. Quadruple equipment. Gear ratio 24:53, 36 inch wheels. Total mileage—244 000. Equivalent to 9.76 times around the world. Revolutions of the armature 301 861 000. Maximum pinion end bearing wear 0.028 inch. Maximum commutator end bearing wear 0.037 inch. Actual time in service—2.5 years.

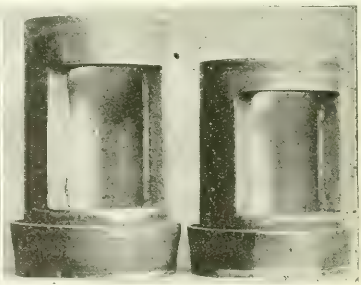

FIG. 18—MALLEABLE IRON SHELL, BABBITT LINED BEARING

City service—some trailer service. Weight of car 25 000 pounds. Double equipment. Gear ratio 15:69, 33 inch wheels. Total mileage—374 941. Equivalent to 14.99 times around the world. Revolutions of the armature 1 054 074 000. Maximum pinion end bearing wear 0.075 inch. Maximum commutator end bearing wear 0.025 inch. Actual time in service 7.5 years.

The Safety Car

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THE STREET car riding public want quick transit from place to place with cars available when desired. Street railways wish to sell their product—transportation—and thus produce revenue to cover usual operating costs, to offset the increased cost of production, due to increases in material and labor and to secure such a return on the investment as will attract capital to the street railway industry.

It may seem paradoxical that both of these desires can be obtained by the use of the one-man safety car, but that this is the case has been definitely proven on a large number of properties in cities of various sizes from the Atlantic to the Pacific. The "safety car" permits increased service without increasing the cost of operation.

About four years ago, the Stone & Webster Corporation discovered that rising costs and jitney bus competition were playing havoc with the net earnings of their properties in the South and West. A careful investigation was made and the solution resolved itself into more service and faster schedules. However, the heavy weight of the old equipments and the cost of platform labor made the cost of the increased service more than the increased revenue. This necessitated an attempt to cut down the cost of operation and thus the light weight Birney safety car was developed through co-operation of the Stone & Webster engineers, the car builders, electrical and air brake manufacturers. The success of the car is fully expressed in the remarks of Mr. H. G. Bradlee* of the Stone & Webster Corporation, that in Houston, Texas, "the increase in car mileage has been 68.8 percent and the increased receipts 41.2 percent; and in Seattle on two lines the increase in car-miles on one line has been 21.4 percent and the increase in receipts 29.5 percent; on the other line the increase in car mileage has been 29 percent and the increase in receipts 49 percent."

Although their operation was eminently successful, there was considerable apathy on the part of the various operating companies, due, no doubt, to the feeling that local conditions in their own cities or towns prevented the use of the standardized car. As city after city in the East and Middle West adopted these cars, it was found that there is not a street railway property in the United States that cannot profitably employ them somewhere on their systems.

It is interesting to note that in 1916, eight percent of all city surface cars purchased were safety cars; in 1917, twenty percent, and in 1918, forty percent. In addition to these new cars, safety devices have been added to a number of older cars so that the percentage of cars with safety devices going into service each year has been still higher.

The standardized car seats 32 passengers when arranged for double-end operation, and 35 passengers when arranged for single-end operation. The safety features, which are inherent in the car design, provide for every emergency in connection with the operation of the car.

1—The car cannot be moved or the brakes released until the door is closed.

2—The door cannot be opened until the brakes are applied and the controller moved to the "off" position.

3—The controller is equipped with a device which requires a conscious effort on the part of the operator to perform his various functions properly.

A single truck is used with an 8 to 8.5 foot wheel base, with 24 or 26 inch wheels. Two 25 horse-power, 600-volt motors are standard equipment on the car. The double-end car weighs approximately 14 000 pounds complete without load, whereas the single-end car weighs approximately 13 500 pounds.

FIG. 1—SAFETY CAR ON THE LINES OF THE NORTHERN CAROLINA PUBLIC SERVICE COMPANY, GREENSBORO, N. C.

In considering the merits and economies of the safety car, it must be emphasized that proper design is of prime importance. It is useless to expect that satisfactory results can be obtained by closing the rear-end of an old style car and taking off the conductor.

The cars are of all-steel construction, measuring 27 feet 9.5 inches over bumpers, and 7 feet 10 inches in width, with continuous steel T-posts, arched roof, steel sides with windows arranged for raising, etc. The bodies are built in one standard form and size. The original cars weighed complete 13 000 pounds, but with the addition of grab-rails at certain points, the use of a little heavier side sheeting, and other minor points, the weight has been increased to approximately 14 000 pounds.

Many features are embodied in the design of the car to provide comfort for the operator and the passen-

*Printed in *AERA*, Nov. 1918.

ger, and to promote safe and efficient operation. The small capacity of the car and the fact that it is operated by one man does away with the need of a large loading platform which, in the past, has invited the rider to linger and thus block the passageway to the inside of the car. With the safety car, passengers are first let off the car before any get on. Very little confusion results for it is only under exceptional circumstances that many passengers get off and on at the same point. In the mornings the traffic is toward town, and at night away from town. In Kansas City, during the rush-hour period, at less than 25 percent of the stops did passengers get on and off at the same point.

The car riders attempt to have the exact fare ready (the percentage runs about 85 percent), for they know that they are holding up the entire car by presenting large pieces of money to the conductor to change.

The car operator is provided with an adjustable stool and, on account of the closeness of the car body to the track, he can sit down to his work, and still have a good vision of the entire track ahead of him. The fare box is on his right, hung on brackets attached to a stanchion in the center of the platform. This stanchion is arranged to revolve so that the fare-box may be swung to the side to permit the operator to pass easily. The register is operated by foot and, in some cases, by an air valve.

The controller and brake valve are on the left side of the platform, so as to allow as much space as possible for the entrance and exit of passengers. The door is 30 inches wide—sufficient to permit passengers to pass in and out in single file.

Cross seats are used throughout on the cars, with grab handles on the seats, which eliminate the unsightly hanging straps. The car is well lighted, giving a bright, inviting appearance.

SAFETY FEATURES

The safety features incorporated in the design of the one-man safety car make it possible to handle heavy traffic with a fast schedule and with a minimum of fatigue to the operator. The real function of the car operator is to sell rides to the public. If he is tired, the inclination is very strong to pass up single passengers at various points on the line. With the door opening devices used, no physical effort is required to make the stop, and additional fares are obtained for the company.

From the standpoint of safety, these features are of prime importance for two reasons:—First, they actually prevent accidents; and secondly, when an accident does occur, the public and the railway company know that everything humanly possible has been done to prevent the occurrence of the accident.

When air brakes are added to a car, the first step has been taken toward higher schedule speeds, towards safety and towards lessening the duties of the operator. If air-operated doors and steps are added, a second big step has been made to reduce standing time, permit of better fare collection, and to diminish the possibility of customers being passed up. Finally, if the entire operation of the car is interlocked together, the highest degree of operating efficiency is reached; the maximum safety in operation is approached; and the car operator can give the maximum of his attention to the track ahead of him and to his passengers, and a minimum of time to the mechanical operation of the car.

Each of these refinements costs money when viewed from the standpoint of first cost only, but when the economies of faster schedules, alertness on the part of the operator and other factors are considered, the first cost is negligible.

From the accident standpoint, the safety features constitute good accident insurance, and the cost of the appliances is merely the premium. Some operators have argued that since no accidents have occurred on their older cars, which were not equipped with safety devices, they are not needed. This is a fatal line of reasoning, for accidents are bound to occur eventually;

FIG. 2—SAFETY CAR ON THE LINES OF THE VIRGINIA RAILWAY AND POWER COMPANY, PETERSBURG, VA.

and the results may be as disastrous as with the big factory that refuses to install fire fighting equipment because it has never had a fire.

THE PUBLIC

The American Electric Railway Association recently sent a questionaire to all railway properties operating one-man cars, asking them as to the attitude of the public on the inauguration of this type of service. The return indicated that the public attitude towards the move was friendly in all but fourteen cases out of the eighty-six companies reporting. The feeling against the car in the case of the fourteen companies has been changed to a friendly one, after a fair trial of the car, in all but three cases. The public is primarily interested in moving from one point in a city to another as safely and as rapidly as possible. Mr. Phillip J. Kealy*, President of the Kansas City Railways Company, stated that the "average rider is not so much concerned with

*In a paper before the Missouri Association of Public Utilities at Excelsior Springs, Missouri.

the size of the unit in which he rides, the type of motors, or the kind of seat, or whether it is operated by one or two men, so long as he is taken to his destination quickly, safely, and at least with sufficient comfort to keep him from being uncomfortable. He would much rather ride the safety car which reaches his corner about the same time he does, than the large unit which does not get there for five, ten or fifteen minutes. Therefore, from the rider's standpoint, the safety car gives him a faster service, a shorter headway and a maximum crowding limit. These advantages very materially outweigh in his mind any ideas which he may entertain as to the comparative difference between the two classes of equipment."

LABOR SITUATION

A great deal of agitation has arisen from labor leaders over the advent of the one-man car, but in state after state these controversies have been settled to the interest of all parties concerned. If the safety car is applied with the sole idea of reducing platform expense,

FIG. 3—SAFETY CAR ON THE LINES OF THE PACIFIC ELECTRIC RAILWAY, LOS ANGELES, CAL.

it is obvious that labor troubles will develop and that public opinion will be against the company. However, if safety cars are applied to accomplish their real purpose—increasing service—an increased number of cars are required, so that actually the number of operators is not materially reduced. Furthermore, the increased rate of pay, which a one-man car operator receives, permits him to make more money than was possible with the two-man cars.

Opposition to the safety car from the viewpoint of reducing the number of men employed is the viewpoint of the middle ages. The rapid progress and development of our country are due largely to the introduction of labor saving machinery of all kinds. Labor has prospered under these conditions. It is obviously an economic error in judgment to impose high expense for transportation on all other workers who use the street cars, merely to carry an extra employe on each street car when he is unnecessary.

TRAINMEN'S WAGES

In their reports to the American Electric Railway Association, 44 companies advanced the pay per hour of their safety car operators, while 25 did not. The increased rates varied from 2 to 10 cents extra per hour, and in two or three cases the increase was somewhat higher. The customary reasonable increase is approximately 10 percent.

Inasmuch as the successful operation of the car depends upon the enthusiastic co-operation of the car operator, he is entitled to share in some of the increased revenue which the safety car makes possible. Furthermore, the increased rate of pay attracts a higher class of operators, and gives the company a man who is more capable of looking after the interests of both the riders and the company.

JITNEY BUS COMPETITION

The light-weight, quick-service car was first developed to combat the jitney bus. Jitneys came into prominence and thrived because they moved faster and because they were waiting at the corner when they were wanted. When this same service was given by the car companies, with a comfortable vehicle, protected from the weather, insuring a safe ride, the jitneys naturally diminished to a very great extent. On the Woodland-LaBranch Line of the Houston Electric Railways Company, over twenty jitneys operated. Six days' operation of the one-man safety car with the decreased headways, drove them all off the line.

ACCIDENTS

After eight months of safety car operation in Dallas, Texas, it was found that but 1.5 accidents for every 1000 miles of operation occurred. During this eight-month period, the twelve safety cars traveled 268 064 miles. During the same period, other types of cars operated in Dallas covered 4 544 123 miles, and reported 2357 accidents or an average of 1.92 for 1000 miles of operation. At the same time, the one-man cars maintained higher schedules than other types of cars in Dallas.

The safety car has a marked effect upon boarding and alighting accidents. This result is logical, for the door and steps are under the direct vision of the operator at all times, and the safety features of the car are such that it cannot be started until the door is closed; and if the door is opened while the car is in motion, the brakes are applied. On a number of large properties, such as the Puget Sound Traction Light & Power Company, boarding and alighting accidents have been eliminated entirely.

In a report of accidents for the year 1918, a large Eastern operating company showed that out of $355 711 paid out in accidents, $23 128 or 12 percent were for boarding and alighting accidents. Persons hurt in this manner on this property numbered 1328. These figures clearly show the possibilities resulting from the elimination of this type of accident.

MAINTENANCE

It is difficult to state the maintenance on equipments after one or two years of operation. However, master mechanics on different properties, by a method of comparison, have established estimates on what the

maintenance per car-mile of the safety car should be. These estimates run from 1 to 1.5c per car-mile and include the overall maintenance of the car body, trucks, motors, controllers, etc.

No definite figures in the saving of track and road bed can be obtained for some years. However, there have been calculated certain savings, such as one given by Mr. T. C. Roderick of the Tri-City Railways Company before the Iowa Electric Railway Association, who said—"A reasonable method would seem to be a comparison of axle tonnage of each type of car over the track, though the hammer blow of a heavier car would be more severe in direct proportion to its weight. The tonnage per axle of the present car is five tons, for the safety car three and one-half tons, while the number of axles per car is two to one. If 50 percent more safety cars were used than of the present equipment, the percentage of axle tonnage would be 52.5 percent, and al-

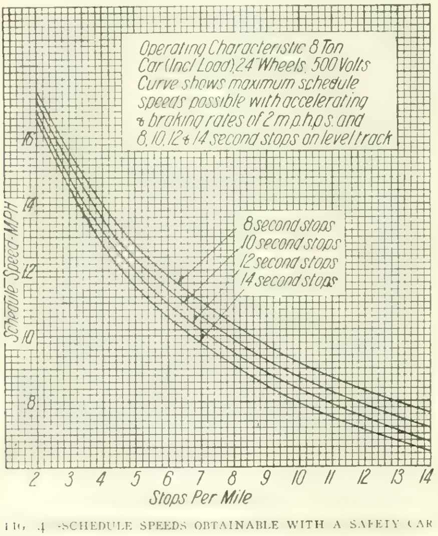

FIG. 4—SCHEDULE SPEEDS OBTAINABLE WITH A SAFETY CAR

lowing 7.5 percent for extra cars of the present type, the tonnage over the track would be 60 percent of the tonnage of the present cars. Applying this percentage to the present cost of maintenance of way and structures would give us for the safety car—60 percent of 0.0208 or $0.0125."

LOAD CAPACITY

The maximum standing load in the car should not exceed 25 to 28 passengers for efficient operation. Actually in emergency 45 to 60 passengers standing have been carried. In Kansas City, 60 passengers (seated and standing) have been adopted as a maximum load and when this capacity is reached, a "car full" sign is displayed. Therefore, a passenger knows beforehand what will be the maximum crowd limit, and that after the car has been filled, it will not stop to squeeze in a few more people, greatly to his discomfort.

DEPRECIATION

A large company operating several hundred safety cars in various parts of the United States, a large number of which have been in operation for over three years, has carefully investigated the matter of depreciation, and estimates that with proper maintenance, the safety car should have a life of at least twenty years; and is, therefore, using a depreciation charge of five percent per year.

GRADE CROSSINGS

The division of responsibility between conductor and motorman at grade crossings has always been considered a grave hazard. The conductor will frequently motion the motorman to go ahead without looking one way or another on the track. The motorman, however, depends absolutely upon the conductor's signal and does not keep on the look-out for a train himself. The Police Department of a middle western city made an investigation on this point and out of 312 cases found that in

19 percent—the conductor looked both ways.
60 percent—the conductor looked one way.
21 percent—the conductor looked neither way.

Inefficient protection is far worse than no protec-

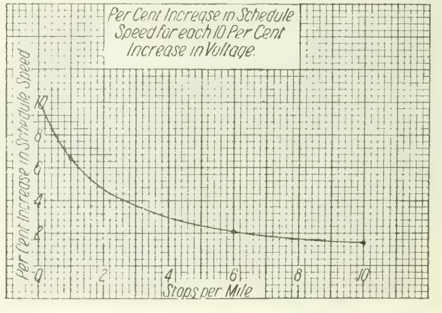

FIG. 5 EFFECT OF INCREASED VOLTAGE ON SCHEDULE SPEEDS

tion at all, and the single responsibility of the safety car operator to take his car across a grade crossing quickly and safely, actually affords greater protection to the public than when the car is flagged across by another person.

The Public Service Commission of the State of Massachusetts permits the operation of the one-man safety cars over steam railroad crossings provided the car is brought to a stop 100 feet from the crossing, again at the crossing, the brakes set, the reverse handle removed from the controller and the operator going ahead to insure himself that it is safe to cross.

SNOW CONDITIONS

The safety cars, in the snowy parts of the country, should be equipped with 26-inch wheels, and lined below the windows. In New England many of the cars have been equipped with scrapers. There is nothing in the design of the safety car which should make it operate less efficiently under snow conditions than other types of light-weight modern equipment. Cars that are designed and built to meet conditions prevailing for

nine months in the year, when there is no snow on the tracks, are poor snow fighters. The only safe and sure way to keep a road open under snow conditions is to provide the proper snow fighting equipment.

ENGINEERING AND APPLICATION DATA

Schedule Speeds—In Fig. 4 is given data on the schedule speeds possible with the safety car, having stops of 8, 10, 12 and 14 seconds' duration with various numbers of stops per mile. During the initial operation of safety cars, it has been found best not to attempt operation at too high a schedule speed. After the operators and the public are thoroughly familiar with the car, it may then be possible to boost the schedule speeds.

Length of Stop—Seven seconds has been found to be a fair average length of stop in city service. With the one-man operated safety car, this average has been taken at ten seconds for purposes of comparison where headways have been reduced with these cars. This is conservative, for when people become accustomed to the method of operation of the safety car, the length of stop does not differ materially from that where doors were closed before the car started. In some recent tests in Kansas City, during the rush hour period, the average length of stop with two different operators was slightly over eight seconds, and the car had a load of sixty passengers during each test.

Stops per Mile—The operation of an increased number of cars, which is the usual practice with the safety car, will tend to decrease the number of stops per mile. While general figures can be given as to the number of stops per mile, it is easier to make an actual service investigation on each line and actually find out the number of stops, and the number of slow-downs Two slow-downs are usually equivalent to a stop.

Voltage Variation—Voltage variation bears an important part in keeping cars on time. The small current taken by the safety car improves the voltage regulation to a very remarkable degree. Fig. 5 shows the voltage variations for use in connection with the curves on schedule speeds, in order to determine what schedules can be made at voltages above 500 volts.

Acceleration and Braking—The limiting feature of acceleration and braking is usually the comfort of the passenger. High rates can be used providing the acceleration and the braking are uniform. The starting resistance of the safety car is carefully designed to accomplish this and acceleration rates of 2.5 miles per hour per second can be obtained without discomfort. The proper manipulation of brakes will give like results with high rates of braking. Even an emergency application on the safety car gives a smooth stop without excessive jar.

The attractive "get up and go" quality of the car, the saving in energy, and the increased schedule speed of the car are all dependent upon these high accelerating and braking rates; and operators must be taught from the first to take full advantage of these essential features. A comparison between acceleration and braking rates of 1.25 and 2 mi. per hr. per sec. is given in Fig. 6. The area enclosed in a speed-time curve is a measure of the distance traveled by the car. In these curves the areas are identical, but due to the more rapid acceleration and braking one car can make the run in five seconds less time.

Power Consumption—Aside from the cost of labor, power consumption is, today, a vital factor in the cost of operation for, with the high price of coal and labor, the cost of power has almost doubled during the past three or four years.

In addition to the actual cost of power, there is also the question of the inadequacy of the present power supply due to increased service required by rapidly growing communities and other conditions. The decreased power consumption of the light-weight car not only saves in the cost of power, but also reduces the investment necessary to produce it. Mr. H. G. Bradlee in his article previously quoted, makes the following statement:— "With these schedules, as we have them here, we estimate a saving of 30 percent in power station capacity; in other words, we are giving increased service, and we have only 70 percent of the peak load we had before, with less number of heavy cars; or having increased the number of cars, it is still possible for us to increase our service some 30 percent more before we get back to the load on our power station, which we had in the first place. So there is quite a material saving in power station capacity and transmission system cost, which you can credit against any general change of this sort.

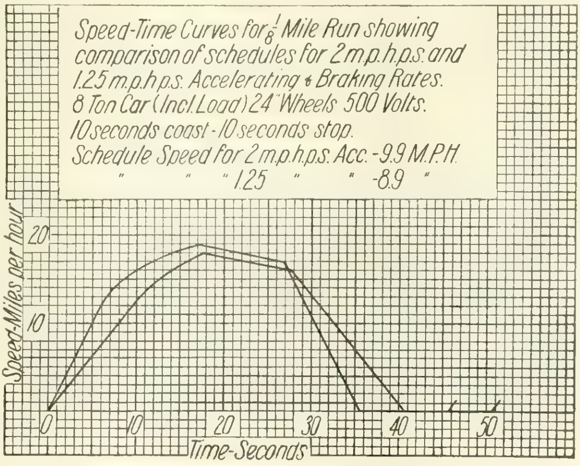

FIG. 6—EFFECT OF INCREASED ACCELERATING AND BRAKING RATES

The power consumption is dependent upon the weight of car, efficiency of the equipment, efficiency of the operator, the profile of the line, the number and duration of stops, and the speed. Consequently no general statement can be made as to the actual power requirements of the safety car. However, if the present equipment weighs, without load, about fourteen tons and a safety car weighing seven tons is put on the same service, the power consumption of the lighter car would be only slightly more than one-half that of the larger car. If the 14 ton car has four motors, then the safety car may actually have less than one-half of the power consumption of the heavier equipment. In the reports to the American Electric Railway Association, the reduction in power consumption where the safety car has been used has averaged 50.2 percent.

Instruction of Car Operators—The success of the one-man safety car depends upon the success of the car operator. This condition makes it imperative that the operator be enthusiastic over the car and thoroughly familiar with its operation and the various duties required of him. A number of different methods have been used to instruct operators in the proper operation of the car, and the method used by the Houston Electric Company is of interest.

Before the first of the cars had been received, six men were sent to Fort Worth, Texas, to the Northern Texas Traction Company, where safety cars had been in operation for some time, to study the car in actual operation, so that they might become instructors of the men who were to operate them in Houston. This party was made up of the assistant superintendent, chief inspector, chief instructor, coasting supervisor and two inspectors.

When the cars were received, about thirty picked men were selected for instruction in their operation. With the assistant superintendent and others of the party, who had studied the situation at Fort Worth, as instructors, these men were trained for two weeks in the operation of the car, without passengers.

After the mechanical operation of the car had been mastered and their preliminary instructions had been completed, some of the cars were placed in service on a shuttle line, so that the operators could get experience in handling passengers on a line where traffic was light. They were kept on these light passenger lines for a week or ten days, depending upon their aptness in familiarizing themselves with the fundamental differences between the two-man and one-man car operation. The trainman on the safety car is known as an "operator" and not as a conductor or motorman. Instead of wearing the customary badge and number, he is equipped with a cap bearing in gold letters the word "Operator." In a frame inside the bulkhead, where it is in plain view of the passenger, is a plate bearing the name of the operator for identification purposes. The object of this is to give the men a personal pride and identification in their work.

The duties of the car operator are more complex than those of a motorman or a conductor, but they are more interesting. The operator seems to feel a certain amount of pride in his being in sole charge of the car. There is no one else to share the praise for good operation or the blame for poor. The ex-motormen appreciate the saving of time they make in stops, because they do not have to wait for a conductor who is slow in giving them the bell, and there are no signals to misunderstand. They also like the coming in direct contact with the passengers. One of the reasons for both former motormen and conductors liking the safety car is the fact that they are kept in a more alert state. A day passes far more pleasantly and quickly for the man who is comfortably busy all of the time than for the one who is busy for thirty seconds out of each minute and is inactive both physically and mentally the other thirty seconds. Finally, the increased pay per hour, which is usually granted the car operators, enables them to earn more money in the same number of hours and tends to attract a higher grade of men.

Care and Inspection—The high schedule speeds, the automatic features of the car and its light construction, make thorough and conscientious inspection an absolute necessity. The operation of the car at its maximum efficiency demands that the air brake apparatus function properly at all times; that the brake shoes be in good condition, and that the piston travel be properly adjusted.

The electrical apparatus, headlights, car lighting, buzzer system, trolleys, trucks, seats, door-operating devices, and car fenders, all require their share of attention.

Inasmuch as the safety car is different from the type of car formerly used, and because it is equipped with smaller apparatus, shop and inspection barn men are prone to neglect it. If the cars do not receive the proper attention in the car barns on the light inspections, more pull-ins will result, and more work will be necessary in the main shop, which creates a congestion there and increases the maintenance cost of the equipment.

The best results have been secured where certain specific men were charged with the responsibility of the safety cars. If this is done, these men take a personal interest in keeping the cars on the road, seeing that they are always neat and clean, and making sure that their equipment is in proper shape.

It is just as necessary to train the shop and car barn forces to take care of the safety car as it is to instruct the operators and dispatchers in the operation of the car.

Electric Railway Freight Haulage

A. B. Cole

THE question of revenue is always of interest in any business, and particularly so in electric railway freight handling. This is true in that there are a number of difficult conditions that should be overcome before the profits in this business can be attractive to some lines.

While both steam and electric railways are freight carriers, there is no logical reason why the rates should be the same. The service rendered by the latter is superior, and should receive compensation that is commensurate with the service given. Many roads have, however, made tariffs with rates less than and others the same as the steam roads.

Interurban operating conditions differentiate the electric and steam carriers to the public. A great gap exists between low and high class freight operating costs on a steam line; for a single locomotive can haul a number of cars and enables the steam carrier to transport heavy carload freight at a very low cost, while high-class, less than carload freight involves a relatively high operating cost, owing to the terminal expense of handling. The exact reverse is true in interurban operation, for here the terminal cost is less than on the steam road, while the haulage cost is much higher. Short haul less than carload business can be handled by an electric line at rates that would involve a loss to a steam carrier. For instance, package freight can be handled for a distance of five miles at a considerably less cost by an electric line than by a steam road; while the steam road cost for a hundred-mile haul is less than that for an interurban.

Considered fundamentally, the rates should be based on the cost of transportation. This cost would include terminal cost for handling, plus road haul, plus the commercial cost of securing the business and for superior service. Taking all costs into consideration, high-class freight interurban rates can generally be lower than those for steam; while the low-class freight interurban rates should be higher than for steam. As practically all interurban freight service is equivalent to either express or time-freight movement, it would seem highly desirable to adjust rates so as to promote high-class freight traffic for interurban lines, and the low-class for the steam carriers.

Many electric railways doubt that the freight business will materially enhance their gross revenue. Why this opinion exists is hard to explain, unless it is due to the lack of system in keeping operating records, or because only a few roads have made an analysis of their freight business and are in a position to know definitely what they are doing along this line.

Economically the electric railway owes the community served the best that it can give towards the development of the natural resources at hand. Passenger travel is essential, but is only subject to the personal desires of the individual; while hauling freight assists in supplying a demand created in different markets for finished or raw products from a given territory. Therefore it is highly important that the economic side of the question be thoroughly analyzed before going ahead, or before deciding not to handle freight.

Arguments brought out against freight haulage are:—A road is solely a high-speed passenger line; another lacks sub-station capacity for hauling freight; or in other cases local conditions will not permit. Usually any one or all of these prove to be fallacious when investigated.

If a road is able to operate a high-speed passenger service, usually it is all the more possible to secure a large freight revenue from such a territory. In this case the question resolves itself into handling the light local freight during the day, and the heavier movements for industries at night, when the passenger traffic falls off.

FIG. 1—TYPICAL FREIGHT INTERURBAN CAR
Terre Haute, Indianapolis and Eastern Traction Company.

Substation capacity need not be a restricting factor, as freight motive equipment now available is designed and built with the idea of keeping the power peaks to a minimum. Slow-speed freight motor equipment can meet the freight motor car and trailer operating requirements, as well as those demanded by heavy night drag freight operation.

If local conditions preventing freight operation do exist, they will continue, as long as the desires of the public are not correctly interpreted by the public officials. Why should the color or shape of a freight car be the same as that of a certain city car? Or freight operation be restricted entirely from some points, because some governing body desires to lay something in the way of the electric line? The public should be made to think the electric way, and it will soon realize that electric railway freight is delivered with despatch, and often at a more convenient point than by any other agency.

Unjust restrictions are imposed on many lines throughout the country by state and municipal authorities. By a proper study of the situation, many a manager, through missionary work, could readily make these bodies see that the electric railway performs an economic service inseparable from the welfare of those whom they represent. This condition can be greatly improved by electric railway operators becoming active in chambers of commerce, and in as many business organizations as possible. This is advisable in order that the business public may find that, as in every other line of industry, there is a personality behind the business. This always casts an atmosphere of success about any business. Aggressive publicity is essential, as the electric railway has a story of service to tell, and it should keep telling it with no apologies.

Merchandising transportation is an important question. Freight transportation is a commodity that must be merchandised. The development of this business is based on the same fundamental principles as the sale of any article by manufacturers and merchants.

FIG. 2—FREIGHT CARS AT FORT WAYNE FREIGHT TERMINAL

TRAFFIC ORGANIZATION

In order properly to develop and foster freight business, there must be some kind of a business-getting department. This is best accomplished through the institution of an aggressive traffic organization, supported by effective publicity and advertising. Moreover, the traffic developed must be handled properly in order to be held. This is only possible through the co-ordination of all freight handling facilities in the territory served, and the complete co-operation of all railway managements involved in through-routing.

Here is where the well paid traffic manager is a valuable investment, for he must not only look after the development of freight business, but also see that there is no break in the service. The very nature of the interurban business requires constant development and care, particularly the less than carload traffic. Where a road cannot at first afford a regular traffic department, at least a good live commercial agent is essential for building freight business. He should be a street and not a desk man, for he will earn his salary many times over, if he understands how to deal with shippers. The business obtained often depends considerably on the personality of the traffic or commercial manager.

Discretion should be used in employing the regular freight solicitor proper, as usually he is of the order taker type, having only a general knowledge of rates; knowing little of the elements which make the service; and less of diplomacy and the salesmanship which is often necessary. In most cases the results of the experienced traffic manager's personal efforts are so singularly superior that solicitors are not needed.

This last means that the traffic manager should not be tied down to details but should be able to start in the morning with a situation report of the previous day before him. From this he would be able to tell at a glance what happened over the whole system during the previous 24 hours. The report would help to give him a basis for his day's work, making it possible for him to see what business should be gone after to bring the greatest return. In many instances, it would be well if the traffic manager could quote a rate on nearly all requests, from his complete knowledge of the situation. There are traffic managers who are able to give quick replies to such questions, and they are the ones that get the business. With a live organization there need not be much fear of the motor truck, as the superior service rendered by the electric line will always win out, because the motor truck is a fair weather carrier.

FREIGHT DEVELOPING

A road should have at least one good terminal city from which the people of the surrounding country are served. Whether or not a freight business will be profitable depends somewhat on the following:—

1—Whether the people depend upon the terminal city as a distributing center.

2—Whether other trading centers are liable to draw trade away from the terminal, due to other railway facilities.

3—The possibility of the establishment of steam road interchange.

4—Industrial development plays an important part in the successful freight operation of many interurban lines.

While many lines were built primarily for passenger service, some of these can readily help develop their communities, and prove of value to themselves by hauling more freight. With this in view, many a line has started by using one or two freight motor cars, each able to haul one or more trailers.

OPERATION

The classes into which interurban freight traffic may be divided are:—

1—*Express and Despatch Freight*—Light packages can be transported in the baggage compartments of combination passenger cars. This is usually handled at express rates or at a fixed charge per package per hundred pounds regardless of class. Properly divided this freight would come under two classes: *a*—Express at a high tariff similar to old line express rates; *b*—Despatch freight, at a rate considerably above the first class freight rate.

2—*Package Express*—Less than carload freight transported on fast interurban express motor cars at regular freight or special tariffs (approaching old line express rates) under regular or special classification.

3—*Fast Freight*—This is a combination of above classes, including the handling of carload shipments daily at regular tariffs and under classification.

4—*Heavy Carload Freight, Switching and Interchange Service*—Under this class come roads doing a regular steam road freight business, at regular tariffs and classifications.

Usually the electric line that has its freight well developed operates a combination service that often includes all or more than one of the above classes. Of course, the kind of service to be rendered can best be determined by a survey of the territory in question. A combination of classes *1* and *3* produces the best results immediately. The business that comes will be of such nature as to provide a continuous amount of tonnage, both less than carload and carload, bringing a profitable return. Such a service is equivalent to the best, and in fact better than steam railroads can give, even under what they call "time freight" service. Class *1* gives a despatch service which is very desirable for medium weight shipments; and in class *3*, there is available a merchants fast freight.

FIG. 3—INTERURBAN MOTOR CAR AND TRAILER
Michigan Railway Company.

However, the fact must not be overlooked, that the most profitable business is the carload. The less than carload freight, which is the kind that most electric lines carry, is expensive to handle, even though an electric line can handle it cheaper than a steam line. A study of steam railroad freight business activities will reveal the fact that carload freight is desired by them, as it yields a fair share of the net total revenue on account of requiring less handling. Some of the reasons why this is true are:—

1—Carload freight is loaded by the shipper and unloaded by the consignee, thereby relieving the railroad company of the responsibility of loading and unloading, and the cost of handling freight in the house.

2—A very large percentage of carload freight is handled at private yards. (This is possible for an electric line, too, where industrial switching has been developed.)

3—For the two above reasons, the risk from loss and damage is very much less in handling carloads.

4—Less accounting is necessary on carload shipments

FREIGHT HANDLING FACILITIES

In order to handle freight at a profit, proper facilities must be provided, including adequate freight terminals, stations and yards according to the character of the business to be done; proper motive power and trailer equipment; mechanical freight handling equipment, and an unlimited amount of imagination.

The very nature of the freight handled by most of the electric lines demands that it be handled with regularity, efficiency and economy. The problem of less than carload freight handling, in interurban terminals especially, requires study in each particular case before an electric line determines how far to go in regard to using mechanical devices. In general, however, it may be said that the four-wheel "dolly", or four-wheel auto-truck will greatly help electric lines to simplify their freight handling. With even such simple devices, the engineers studying this problem have found an appreciable reduction in the cost per ton of freight handled. With a four-wheeled auto-truck one man can move from 2000 to 3000 pounds, as compared with 400 to 600 pounds on a two-wheeled hand truck. At least four-wheeled push trucks should be used wherever possible at the start. Proper team yard facilities are essential in order to handle very much carload freight, and in such yards there should be a crane of some type to lift heavy freight.

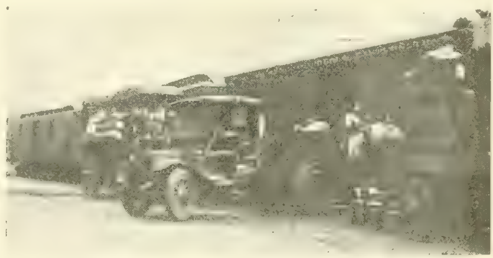

FIG. 4—LOADING CARLOAD FREIGHT AT INDIANAPOLIS
Terre Haute, Indianapolis and Eastern Traction Company.

FREIGHT TERMINALS AND STATIONS

Where there are several terminal cities, each should have a freight terminal laid out according to traffic requirements. Usually when the business demands, there should be at the main freight terminal three necessary units,—an inbound freight house, an outbound freight house, and a team yard. The in and outbound houses should be opposite each other, with from three to five tracks between them. Where there are only two tracks, there is generally congestion, unless the layout is for stub-end operation. Adjacent to the house tracks at one end of the terminal yard should be the team tracks, long enough to permit the simultaneous loading of several freight cars.

In parts of the country where the dairy business is profitable, a track is reserved for the milk car or cars. A storage track for empty cars may also be desirable. Along the above general plan a terminal for from 10 to 100 cars can be built.

In operating a terminal it is possible to use all its units to advantage; for instance in many cases where there is a heavy daily merchandise movement to a certain point, enough to make up a car, this car need not

be "spotted" on the house track, but placed in the team yard. Thus, the house track has been relieved of one car. As there is a checker on the team track, teamsters can be directed to the car in the team yard. This illustrates one advantage of having proper terminal facilities.

ELECTRIC TRAP CAR SERVICE

Trap car operation means that certain industries are called upon by one or more freight cars each day, collecting small less than carload shipments. The trap car can be one or both of two forms, a small trailer or a motor car of the platform type with a cab at one end. The trailer can be moved readily from industry to industry for large less than carload freight shipments; while the motor car can pick up a large number of smaller shipments. One-man trap cars could be used in many places resulting in the collection of freight that would not have been secured otherwise.

ROLLING STOCK

Regular electric freight motive power equipment is essential. To begin a freight business, one or two freight motor cars are required, and these should be able to haul at least one trailer apiece. As business develops, it will be found to advantage to have two or three trailers available for pushing the carload business. One road, with only five motor cars and six box car type trailers in one month recently handled 2578 tons, or 234 tons each, at 15 tons per car, so that each car handled approximately 16 loads in the month of 25 days. This is getting good use out of the equipment, and shows what can be accomplished with a small amount. When operating a freight motor car and one or more trailers, the motor car can act as a peddler or merchandise car, while the trailers with carloads can be set out at any station.

FIG. 5—A WELL LAID OUT SMALL FREIGHT STATION

Chicago, Lake Shore and South Bend Railway.

A road starting as above mentioned, will need later, motor cars capable of hauling three or more trailers, as business demands. In case an extensive steam road business develops, and becomes heavy enough, an electric locomotive would best serve the purpose. This is especially the case where an electric line needs equipment to handle reasonably large "cuts" of cars left on interchanges in one train movement, as then the expense is held to a minimum.

Motive power equipment is available which has such characteristics that operating an "off peak" freight service would not necessarily require any additional substation, power house or feeder capacity; or in any way interfere with regular traffic. Low-speed field control locomotive motors can handle heavy drags of cars with no greater power demands than those required by a single large high-speed interurban passenger car.

For efficient freight operation, whether the motive power equipment is placed under a flat car or a regular electric locomotive, there must be some differentiation in the design from that for passenger propulsion. The use of passenger motors should be entirely eliminated when considering freight service. In using this equipment, speed is obtained at the expense of power, and the fact that many roads operate motor-freight cars on practically passenger schedules has led some to believe that all freight service exacts a large amount of power. But freight trains need not move at passenger speeds.

RECORDS

In conducting a freight business, it is not only imperative that records be kept of shipments as protection against claims, but also, for the intelligent operation of the service. Thus a simple, but adequate accounting system is necessary. Many roads find that standard steam road billing and accounting methods are the best, with modifications where necessary.

FIG. 6—INTERURBAN TRAILERS "SET OUT" FOR LOADING
At Indianapolis freight terminal.

OPERATING STATISTICS

Freight operating records should receive more careful attention than they usually do, and in charging expenses to the freight department, nothing should be added that does not belong against freight operating. A few simple records, as given below, will in time tell an interesting story of the freight operation on a road.

Gross freight revenue
Expense of freight service
Net freight revenue
Revenue tonnage by stations
Total system revenue tonnage
Revenue freight car-miles
Revenue per freight car-mile
Operating expense per motor freight car-mile
Operating expense per trailer freight car-mile
Ton-miles operated
Revenue per ton-mile (motor car)
Revenue per ton-mile (trailer)
Combined system revenue per ton-mile

Overloads in Railway Motors

F. W. McCloskey
Railway Engineering Dept.,
Westinghouse Electric & Mfg. Company

IN ADDITION to handling the normal traffic, railway motors are occasionally called upon to perform emergency service such as pulling in a "dead car", pulling a car back on the track, etc. It is important in such emergencies that the equipment be able to pull out of the trouble and get out of the way of other cars as to avoid a tie-up in traffic. The resulting damage to the motor, due to overload, is generally of secondary importance in such cases, unless absolute failure occurs, because the avoidance of a tie-up in traffic more than offsets the shortening of the life of certain working parts that results from the overload.

MECHANICAL FAILURES

A mechanical failure seldom occurs during such overloads, since a current that would develop enough torque to stress any of the working parts up to the rupture point or even the elastic limit, would burn up the windings. Slippage of wheels also definitely limits the mechanical stresses obtainable under a starting overload. So, as a rule, under such conditions, barring of course the possibility of defective material, the limit from an insulation standpoint is reached long before the mechanical limit.

Probably the greatest mechanical stresses that can be applied are those which occur when a motor is reversed while going at high speed. The overload trip does not protect the motors in this case because, as a rule, it does not act quickly enough to limit the current. Tests have been made which show that under this condition the torque developed may be as high as twenty to thirty times normal. Flashing or "bucking" over of motors is another cause of bent or broken shafts.

Many cases of broken shafts, which are commonly attributed to so called crystallization of the material, are probably due primarily to the shaft becoming bent at some time, which results in the repeated stressing of the outside fibers a little beyond the elastic limit. This results in a crack, which gradually progresses until complete fracture occurs.

ELECTRICAL FAILURES

In some of the older types of motors without commutating poles, flashing-over at the commutator under heavy loads was frequently the principal limit in such operation, particularly if, as was often the case with this type of motor, the commutator and brushes were not in good condition. The flashing would burn field coil terminals and leads and damage the insulation of both the field and the armature windings. Matters would go from bad to worse, resulting finally in short-circuit or ground or inability to keep the circuit breaker closed. This was not true of all of the older motors, as some of them, in spite of lack of commutating poles, had fairly stable characteristics, and gave a very good account of themselves under such conditions.

With the addition of commutating poles, and proper proportions in design, flashing as a rule ceased to be a limit in emergency service. A well-designed motor should easily handle, without flashing, any loads which the insulation will stand.

Perhaps the greatest electrical overloads that a railway motor is called upon to carry, occur in bucking snow. This is a type of overload that should, for the most part, be classed as avoidable. The starting and stopping, backing up and going at it again, constitutes a cycle of operations which is particularly hard on the insulation. Heavy currents, amounting to several times what the motor will stand continuously, flow through the windings. Lack of ventilation limits the carrying away of heat from the windings. In the non-ventilated types, the natural draft of air which takes place in the normal operation of the car is absent, on account of the very slow speed. In the ventilated types, the effectiveness of the fan is practically nil, for the same reason. The result is that the temperature of the windings depends almost wholly upon the ability of the iron parts surrounding them to absorb, rather than to radiate heat. For example, if a certain amount of heat flowing into a mass of metal, raises its temperature 50 degrees, the same amount, applied to a mass of the same material twice as large, will raise its temperature one half as much, or 25 degrees. This is on the assumption that no heat is radiated in either case. When heavy overloads are applied to a motor for relatively short periods of time, the heat is generated faster than it can be carried off by radiation. The resulting temperature at the winding will, therefore, depend very largely upon the weight, or more correctly, the mass, which is proportional to the weight, of the surrounding parts, since the larger this mass the cooler it will be and the more rapidly will the heat flow to it from the windings. Thus the ability of a motor to stand up under such conditions is fundamentally more a matter of size than of design.

A point frequently overlooked is that the damage done to the windings under the above conditions often does not show up at the time of the overload. This frequently leads to the conclusion that since the motor "got by" it suffered no permanent damage. This is a mistake. The insulation is generally weakened and a failure directly traceable to this particular overload may occur months afterward, when the history of the case has been forgotten.

In this respect insulation differs from some of the mechanical parts. If the stress in a shaft exceeds the elastic limit of the steel, permanent bending occurs

immediately and failure is not far distant. The characteristics of steel are such that the amount of this stress will not be much greater than that which the steel would stand continuously. The limit of load is therefore quite sharply defined, the range between safe and unsafe stress being approximately 10 to 25 percent.

Insulation on the other hand has, under certain conditions, a considerably broader range of possible operation without immediate failure, even under excessive temperatures. This is partly due to the fact that often the final failure is the result of continued vibration, rather than of a decrease in insulation resistance, due to roasting. The latter however is the primary cause of the failure, because of the consequent mechanical weakening of the insulating fabrics.

Permissible extent of overloads depends upon the kind of insulating material used. Fibrous materials, such as cotton, cambric and paper, will not stand as high temperatures as mica for instance. The kind of material used, in turn, is often dependent upon such considerations as the size of wire, voltage, space limitations, etc. In motors for city service, it is usual to employ fabric materials as the principal constituents of the insulation on the windings. This class of material is good for continuous operation at a temperature up to 100 degrees C. Around this temperature charring commences and the life of the insulation is materially shortened if worked above this temperature. The penalty of overloading motors to take care of emergencies is shorter life of insulation. Only in unavoidable emergencies is this justified.

Time is an important factor in the disintegration of insulation. Fresh cotton insulation, suitably impregnated, will stand 150 degrees C. for a few minutes; whereas 125 degrees C. will gradually weaken it. In time, the impregnated material becomes dried out, the insulation is much weaker and more susceptible to failure under vibration, due to loss of flexibility. Cracks more quickly develop, thereby reducing the creepage distances. Pulverizing of the insulation is also liable to result in grounds or short-circuits, this condition being aggravated by the fact that charred cotton is a conductor. Thus the ability of a motor to handle overloads depends largely upon the greenness of the insulation, as well as upon its capacity to absorb heat rapidly.

While the above statements on the effects of overloads apply to both types of motors, they are true to a greater degree in the ventilated type. This is because the volume of metal, including copper and iron, is considerably less which, as pointed out above, largely determines the capacity of the motor for absorbing heat on a short-time overload. Comparing ventilated and non-ventilated motors having the same continuous capacity, the former will have about 60 to 75 percent of the weight, or volume of the latter. Its heat absorbing capacity is in about the same proportion. Under an overload, such as in bucking snow, the amount of heat carried off by the fan is almost negligible because of the slow speed. Therefore, the temperature will depend almost entirely upon the masses surrounding the windings, and will be higher in the ventilated than in the non-ventilated type, due to the greater mass of the latter. On the other hand, the two types of motors would reach about the same maximum temperature in normal service, in which the fan becomes effective.

In the usual application of motors, a reasonable margin is allowed to take care of emergencies. But if a motor is expected to perform the heavy duty imposed when bucking snow, in addition to handling the regular service, a much heavier motor should be used. Such an arrangement, however, would be expensive in the long run becauee of the greater initial investment and because of the greater weight to be carried around. This cannot be justified by the relatively small proportion of the year that the heavier motor capacity is actually required. Furthermore, there is considerable to be said against applying a motor which operates too cool under normal conditions, as it does not keep itself dried out. The resulting accumulation of moisture is a deadly enemy to the insulation, as has been thoroughly proven in practice. The logical, and most economical proceedure, therefore, is to have and use liberally, efficient snowplows and sweepers to keep the tracks clear.

The exceptionally severe winter of 1917-1918 demonstrated one thing quite conclusively, viz., that those properties whose snow fighting apparatus was well tuned up, and in liberal quantity and liberally used, had comparatively little trouble due to snow. On one property it was the hobby of the general manager to order out the sweepers at almost the first snow flurry, much to the dissatisfaction of some of the men. Perhaps this manager leaned backward a trifle, but his troubles due to snow were comparatively few.

The failure in many localities in this respect was not due to lack of spirit or individual efficiency on the part of those immediately in charge of the equipment. Rather it was due to lack of efficient apparatus, and lack of organization. It is not at all uncommon to find that some of the snow sweepers are twenty to thirty years old, and equipped with motors fully as ancient. Experience has proved that frequently these sweepers, when called out in a storm, get only a little distance before they themselves must be pulled in.

During 1917-18 a great deal of trouble was due to inability to obtain necessary materials, such as brooms, to put the sweepers in better condition. With the lifting of embargoes, etc. this difficulty has been for the most part removed, and recent inspection on several properties visited indicate that better preparations are being made along this line. This augurs well for the maintainance of normal service during the coming winter months. This subject deserves the closest study by railway managers, for it has been amply demonstrated that efficient snow fighting equipment, with well organized operators behind it, is a paying proposition.

Automatic HL Control for Boston Surface Cars

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THE traction conditions in a modern large city with its congested streets, and the consequent need for trailer or multiple control train operation, quick starting and stopping, and above all for every precaution which will ensure safety under all conditions, require cars that are especially adapted to meet these conditions. An installation which represents the best modern practice along these lines is that of 100 of the center entrance, low floor city cars now being placed in service by the Boston Elevated Railway Company. The appearance of this type of car is shown in Fig. 1 and the principal dimensions are given in Table I. They are equipped for double-end operation, having center entrance doors on both sides.

The control system adopted employs battery operation with a train-line for multiple-unit control and provides automatic acceleration by means of a separate "sequence switch." A sequence switch is essentially a remotely operated device in the nature of an automatic master controller for the main motor-controller box, being governed in turn by the master controller and subject to the action of the usual accelerating current limit relay.

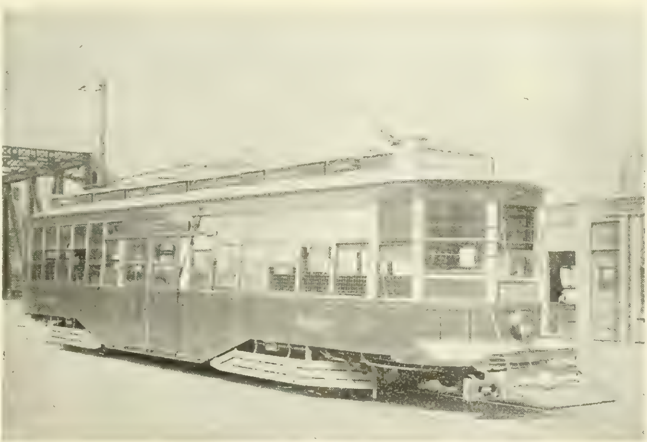

FIG. 1—LOW FLOOR CAR USED ON THE BOSTON SURFACE LINES

TABLE I—PRINCIPAL DIMENSIONS AND DATA

Length over anti-climbers	48 ft. 0.5 in
Length between truck-centers	24 ft. 0 in.
Width overall	8 ft. 0 in.
Height over trolley hook	12 ft. 0 in.
Wheel-base of truck	5 ft. 6 in.
Wheel diameter	24 in.
Weight, completely equipped	43 000 lb.
Weight of motors and gears	6 800 lb.
Weight of control equipment	1 300 lb.
Seating capacity	58

The cars are for operation in fast city service, and in order to facilitate their use in multiple-unit trains, automatic car couplers have been provided, which combine the air and electrical train line connections. As the cars will run on tunnel routes eventually, they have an emergency lighting provision which automatically cuts in a reserve circuit of lamps supplied by storage battery. This occurs whenever the trolley pole leaves the wire or power has been otherwise lost to the regular marker lights.

Rapidity of train and car movement is aided by the installation of automatic starting signals, effective upon closure of the doors. The center-entrance doors are of the sliding type, 6 ft. 6 in. total width, operated by air engines with manually controlled valves. The conductor's stand and motor-driven fare-box are located in the central well. This is reached by a 15 in. step from the outside. There is a 10 in. rise to the floor level at either side of the well, and moderate ramps increase the total difference between rail and floor to nearly 31 inches at the trucks. The greater number of seated passengers are accommodated on transverse seats of the reversible pattern. There are a few longitudinal seats, and the space at the car ends is also utilized when not required by the motorman.

MOTORS

The propelling equipment consists of four motors rated at 40 hp at 600 volts. These motors are of the standard box type with a special suspension adapted to the trucks. The inside hung arrangement is employed with leads at the axle side. Commutator covers and gear cases are made of pressed steel. 42 tooth gears of the solid cast steel type are used with 15 tooth pinions.

BRAKE AND AIR EQUIPMENT

A motor-driven air compressor is located at one side of the car between the center-entrance well and the truck. There are two 12 by 54 in. main reservoirs located beyond the truck, hung transversely under the overhanging end of the car. A separate 10 by 14.5 in. equalizing reservoir is provided together with other auxiliary pneumatic details for the air supply to the control apparatus. Across the car from the compressor next to the well is located the 10 by 8 in. brake cylinder, a countershaft, sheaves and chains for the hand brake connections to the brake rigging. Nothing is mounted under the weil, except brake chains and piping.

LOCATION OF ELECTRICAL APPARATUS

Near the compressor is located the regulating apparatus for the storage batteries. 18 Edison cells give a nominal operating voltage of 24 for the control and auxiliary battery circuits. The batteries are located above the car floor, under two of the transverse seats.

All other apparatus mounted under the floor is located across the central well from the air brake apparatus. The main controller box is hung crosswise on the same side of the car as the air compressor, and the sequence switch is at the other side. A trap door is provided in the floor to enable the operator to manipulate the reverser and motor cutouts, described later as part of the controller box. The grid resistors are under the other overhanging end of the car, in a position corresponding to the location of the air reservoirs.

In the ends of the car the control switches and master controllers are located as usual for each motorman's stand. Close to the master controllers at the floor are junction boxes, conveniently arranged with vertical terminal boards for the various control connections. Multi-conductor cables lead from these junction boxes to the train line couplers, and to various parts of the car. The lamps of the door signal circuit are used to illuminate the air-pressure gauges, being mounted near the brake valves. The latter are arranged for electropneumatic operation of the air brakes in conjunction with application and release magnet valves on each car, control train line wires for their operation being accommodated in the main automatic couplers.

At the central part of the car is another connection board for auxiliary circuits, near a distributing panel with fuse cutouts for the lamp, signal, and control circuits. The main light, compressor, and heater switches are located at the center of the car, together with two signal bells and the service buzzer.

It will be seen from Fig. 1 that current is collected at the forward trolley pole. This method of operation, exactly the reverse of ordinary, has been adopted after a considerable trial period. The trolley rope is thus put under control of the conductor. The use of the hook to lock down the unused trolley pole forms a unique interlock; the line relay connection is taken from the hook so that the control can not operate unless the second trolley pole is down.

CONTROL BOX

The main motor control consists chiefly of eight unit switches of the electro-pneumatic type, each with its operating magnet valve, and air cylinder. Eight strap wound coils adjacent to the switches furnish an effective magnetic blow-out. The main circuits, which are of the well known *HL* type, have shunting transition and starting resistance combinations to secure nine steps total, the fifth and ninth being the running points in series and parallel respectively.

In construction, the group of eight switches is mounted in a box between two end plates, the latter constituting compartments in themselves, which house the main reverser, the overload trip, and other parts, as shown in Figs. 2, 3 and 4. One controller box thus accommodates practically all apparatus

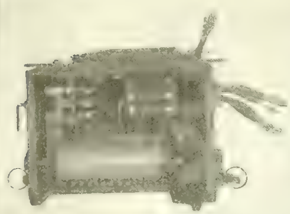

FIG. 2—REVERSER END OF CONTROLLER BOX
Showing also the motor cutout panel.

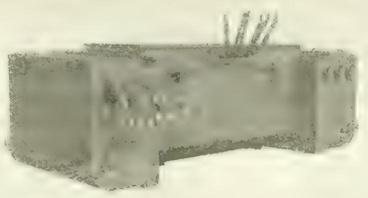

FIG. 3—GENERAL VIEW OF CONTROLLER BOX FOR HL AUTOMATIC CONTROL

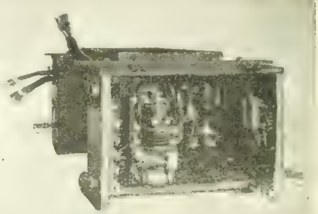

FIG. 4—RELAY END OF CONTROLLER BOX
Showing combined overload trip and line relay, the limit relay and the notching relay.

required for the control of the four propulsion motors. The dimensions are such that adequate clearances are obtained with 24 inch wheel, low floor cars. The construction complies with the important requirement that the arcing chambers be separated from the control circuits and the main power wiring, which are isolated in suitable compartments. But three switches have interlocks, these being necessary for the protection of the line switch, series and parallel switches.

UNIT SWITCH CONSTRUCTION

A "cut-away" view of one of the light-weight type air cylinders and details is shown in Fig. 5. The piston insulator and switch hook employed secure a considerable reduction in overall height in comparison with other designs. An operating magnet valve of familiar type is also illustrated in Fig. 5, which shows the enclosed coil, moving parts, valve ports and the air passages. All details include the latest developments and improvements in mechanism for effectively using compressed air in the operation of main circuit controlling apparatus.

One point of particular interest in Fig. 6, illustrating the actual switch elements, is the ingenious arrangement for dis-assembling the arcing box. The sides may

be removed by displacing spring clips, and the upper arcing block is then readily removable. It is supported and retained by the sides, no other fastening being necessary. Further, the lower arcing block can be withdrawn after loosening the single bolt and nut which are entirely accessible. This construction renders it very easy to replace in a short time any part of the arcing box which has gradually burned away.

As shown in the upper view, Fig. 6 certain switch units are provided with long arc chutes which extend through the main cover and are protected by weather shields. One of the two units so furnished for this controller box is the line switch, *LS* in Fig. 9, which is subject to circuit breaker duty from the action of the overload trip. The gases arising from the arc breaks at the line switch in regular operation are thus exhausted to the open, preventing an accumulation in the switch group chambers. The chief resistance switch *R1* is similarly provided since it especially reinforces the line switch in the interruption of power at the first notch.

Another improvement in details of the switch construction is in the main terminal bolts of the switch unit. The hexagonal head of the bolt which secures the switch itself to the supporting plate and insulation is

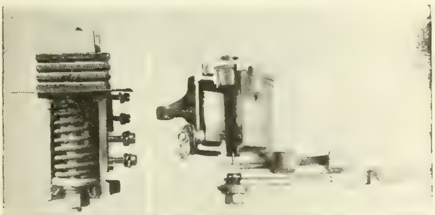

FIG. 5 CUT-AWAY VIEW OF OPERATING AIR CYLINDER AND OF VALVE MAGNET FOR UNIT SWITCH

made extra large in order to receive a tapped hole. A shorter bolt, concentric with the former at the top, is used to secure the cable terminal or copper strap connector leading to other switch units or blow-out coils. Assembling the switches by this method insures reliable contacts between the connection straps and switch parts, and has the added feature of permitting adjustments without disturbance to the fastenings of the switches themselves.

REVERSER AND RELAYS

The most important of the associated main circuit apparatus in the control box is the reverser, shown in Fig. 2. It is located in one end plate box and operated by an air cylinder similar in construction to that employed for the operation of the unit switches. Heavy plates and copper tipped fingers are provided to commutate the connections for the four motors. The shaft of the reverser drum carries a handle on the outside of the box so that the reverser can be operated easily by hand. Another convenience is a door above the reverser handle giving access to the knife-switch motor cut-outs. This makes it possible to cut out a pair of motors readily should a motor become disabled.

In the end plate box at the end opposite to the reverser, a terminal board is provided for connections to the internal control wiring. The important parts mounted at this end consist of the line and overload trip

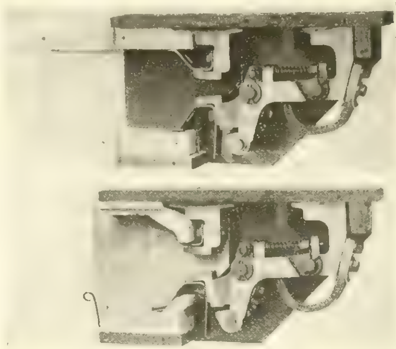

FIG. 6 LIGHT WEIGHT TYPE UNIT SWITCH
Cut away to show operating mechanism.

relay, the current limit, and notching relays, shown in Fig. 4. The first is a combination relay, having a shunt coil connected to the line and a series coil which carries total car current. Its contact disc is normally operated by the shunt coil, but overload current through the series coil causes an armature to lift and lock itself, raising the contact disc simultaneously. The control circuits interrupted consequently cannot be restored until the trip is reset by action of the small reset coil at the bottom of the relay. The current limit relay is of the solenoid and plunger type with a single contact disc. In connection with the limit relay there is the notching relay which has certain contacts to by-pass the limit for one notch at a time. This notching relay is illustrated in Fig. 7 and its action will be further described under operation.

TRAIN-LINE CONTROL

A control cutout switch and a master controller, Fig. 8, are located in each motorman's cab. Combined with the control switch is the reset switch, so that all

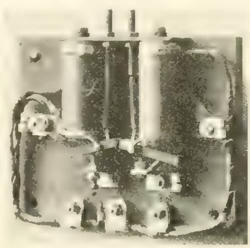

FIG. 7 NOTCHING RELAY

control is thrown off when resetting. Special master controllers were designed in order to accommodate signal, lighting, and auxiliary circuits. Extra fingers and contacts are incorporated in the reversing drum

which give the master controller a directional function in a double sense, since it serves also to select the proper combination of bell and buzzers, head and tail lights, and door signal lights, besides governing the forward or backward motion. Interlocking for the door signal circuit to correspond to the three conditions of head end, coupled end, and rear end is determined by the position of the reverse handle, in conjunction with a cut-out switch on an air cock in the brake train line.

The master controller has its main drum arranged for motion in one direction from the *off* position to which it is returned by a coiled spring. Mechanical interlocks prevent conflicting movements of the reverse and main drums. The usual automatic notches are registered, namely, a first or switching position, and the series and parallel running points. The scheme of connections requires that three train-line wires be operative in order to secure, or to maintain, power through the main controller box.

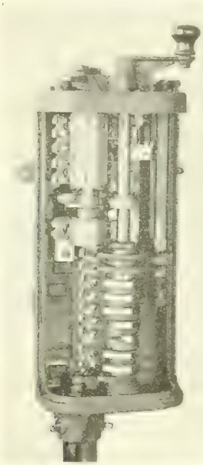

FIG. 8—MASTER CONTROLLER

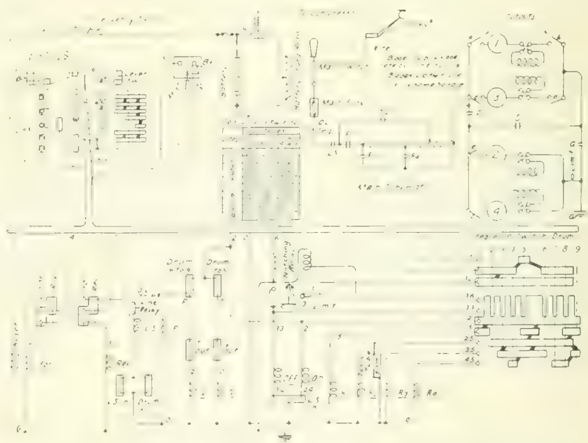

FIG. 9—SCHEMATIC DIAGRAM OF MAIN AND CONTROL CIRCUITS
For HL automatic control for four 600 volt motors.

Should an extreme emergency exist due to deranged control circuits, and providing that nothing is accomplished by throwing the master controller into reverse, the battery (and fuse) may be short-circuited as a final interruption for the control supply. This function is so interlocked as to be prevented under normal conditions, being obtained by a push button which is located at the back side of the master controller top. At the right hand side under the main handle there is an auxiliary handle which is indicated in Fig. 9 as a lever switch in the master controller. Manipulation of the lever switch while the main drum is held in an *on* position secures notch by notch acceleration at currents exceeding the limit relay setting. This is obtained through the medium of the notching relay previously noted as part of the main controller.

SEQUENCE SWITCH

The sequence switch consists of an air engine operating a cylindrical contact drum, which effects the desired connections for the control circuits at suitable contact fingers. An electro-pneumatic operating cylinder or air engine of the *PK* type* is employed. The usual *on* and *off* magnets regulate the movements of the double-ended piston by means of the balanced air-pressure principle. An improved driving mechanism is provided, and is so arranged as to produce an exceptionally compact construction, as shown in Fig. 10. The bearings are of an enclosed type in order to retain the lubricant. In addition to its use on the Boston lines, this type of sequence switch is also being adopted on various other railway properties throughout the country.

Two distinct functions are performed by means of the connections at the sequence switch; some being used to regulate the action of the sequence drum itself, and others having direct connection to the switch group magnets, thus transferring the control to the switch group which results in the desired acceleration.

Action of the sequence drum can only be initiated by the master controller. When started, the drum automatically advances, contingent ordinarily upon the performance of the accelerating limit relay, and proceeds to the step indicated by the master controller. At any time the progression of the drum may be checked or all control shut off. The master controller, in backing off, releases the sequence switch magnets so that the drum starts at once to recede to its *off* position. Of greater importance, however, is the fact that the train line circuits, when de-energized by the master controller, directly drop the switch group magnet coils connected at that particular time, causing all switches to open at once, independent of whatever position the sequence drum might have.

*See articles in the JOURNAL for Oct. 1914, p. 570 and Oct. 1917, p. 436.

OPERATION

The preceding descriptions give sufficient knowledge of the apparatus to enable the schematic diagram, Fig. 9 to be followed. However, some inter-related features which insure safe and positive operation of the control can be best explained by direct reference to the diagram.

Tracing *B2+* to the master controller reverse drum, and either *4* or *5* shows that the usual reversing function is carried out by means of interlock contacts on the main reverser, and three fingers and contacts of the master controller. Although the *2* wire, also energized at the switching notch, results in the closing of *S* and *R1* switches, by way of *15* and *22* wires through the sequence drum, it is necessary that the reverser and line relay contacts be properly set before the circuit to the line switch magnet, coil *LS*, can be established.

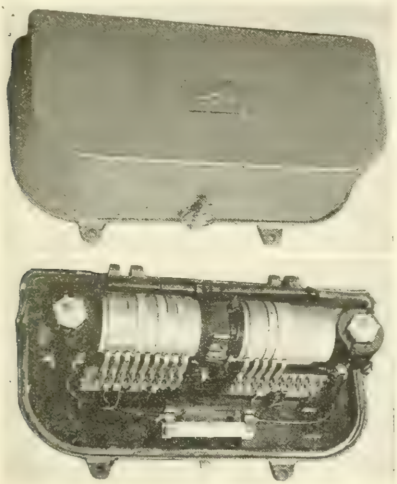

FIG. 10—SEQUENCE SWITCH

Also a second fundamental requisite is the operation of interlock drum *1*, before the circuit is completed to *0* wire and back by the master controller. This fulfills the essential that the first application of power must occur on step *1* preparatory to further progression. A holding interlock on *LS* maintains the connection when the sequence drum has left the *drum 1* position.

The line switch directly affects the progression and return of the sequence drum. It is readily realized that if the line relay or overload trip opens the line switch circuit, the dropping out of the *LS* interlock results not only in preventing a re-establishment of the circuit until the sequence drum takes up the *1* step, but is also the means of causing the drum to return, since both sequence switch magnets are de-energized.

Consider next the progression of the drum and the resulting acceleration caused by the operation of the *R2* and other switch units in the desired starting order. The sequence drum automatically controls the series parallel transition, just as it does the resistance notching. Movement of the drum depends on a circuit through the *1* wire and sequence drum to the *off* magnet, by implication that the limit has dropped, the car having attained a sufficient speed and reduced current. The limit, under influence of the motor current as it varies on the notches, causes successive operations of the *off* magnet. The *on* magnet is energized continuously from the *2* wire, and admits air ready to advance the drum notch by notch as the pressure in the *off* cylinder is intermittently reduced and restored. In this way, the full parallel running point is finally secured if it is the will of the operator to advance beyond full series, in which case the *3* wire will be energized.

In taking a notch, an auxiliary contact is made through finger *33* and contacts on the drum, which insures that the movement is continued far enough to attain the proper position on the drum. This action aids in arresting the motion accurately, so that the drum moves with precision.

Previous references have been made to the notching relay which comes into action through operation of the lever switch in the master controller. This causes the notching relay coils connected to train line wire *6* to lift the left-hand relay armature, which by-passes the limit contacts. At the same time, however, the sequence switch, in its positive movement to take the notch, energizes the right-hand coil of the notching relay and opens the circuit. Although this coil is de-energized as soon as the sequence drum stops at the new notch, the motorman's lever switch must be dropped off in order to release the right-hand relay contact arm. This is due to the design of the magnetic circuit, which makes the left-hand coil serve in effect as a holding coil for the right-hand contacts.

CONCLUSION

This installation by the Boston Elevated Railway Company is notable in providing for the multiple-unit operation of city cars where a private right-of-way is employed in the more congested district. The equipment complies with the recognized essentials of safety, convenience and speed. Besides the provision of efficient car specialities and a thoroughly worked out scheme of auxilaries operated from an independent low-voltage control source, the car is equipped with a fully protected, automatic motor control.

This form of control has been obtained with an exceptionally small amount of reliable apparatus. At the same time the control scheme, based on the use of the sequence switch, provides many desirable operating characteristics, illustrating the fundamental features of automatic operation reviewed in itemized form below.

1—Shutting off control de-energizes all the circuits and the switches open simultaneously, all apparatus taking up an initial or *off* position, as a necessary preliminary to further action.

2—The line relay function acts upon partial or complete interruption of power to return all apparatus to the initial position. The same protection is secured on overloads, with the further necessity of resetting the overload trip.

3—Two and three wire control.

4—Application of power is obtained only after the reverser is properly thrown and the line switch is closed.

5—Progression is dependent upon the closing of the preparatory switches and then it can only take place according to its predetermined sequence.

6—Parallel switches are fully interlocked against series switches.

Finally, the convenient arrangement of the apparatus described, and the method of operation with safety and protection result in an equipment of an admirable type for high-speed city service.

Local Associations for Organization Betterment

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Westinghouse Electric & Mfg. Company

The advantage of having local organizations to discuss better ways and means for reducing operating costs and improving service has been a subject of paramount interest to railway organizations for many years. Opinions from authorative students and successful managers seem to be divided on its profitable scope in railway organization, with citations of glowing examples to substantiate each contention.

Theoretically a well organized railway company, with properly selected department heads, efficiently supervised, should function perfectly, but experience in practice has shown that even with all of this, the desired results are not always secured, necessitating modifications which usually result in the adoption of some form of department or general meeting plan.

Internal meetings of a railway organization are generally classified as educational, operating or political, with the necessary modifications or subdivisions to meet local requirements. Operating meetings are permanent fixtures of the organization, held weekly between the management and departmental heads, departmental heads and their immediate subordinates, and in some cases are extended to include the entire departmental personnel. The educational and political meetings are of a temporary nature, generally planned to meet special conditions, and as a rule are confined to one or more departments.

After the past few years of exceptionally trying operation, emphasized by the loss of experienced employees, continued increasing costs of labor and material, and a non-appreciative press and public, unwilling to grant proper compensation for present service, some managements have grown skeptical of any appreciable reduction in operating costs or improved service. Others have weathered the storm, perfecting an organization which has been strengthened by contact with local railway associations, committees and sub-committees with whom the management may take counsel on important subjects with the assurance of a thorough and conservative consideration of all recommendations.

One of the prime advantages of such associations is the mutual confidence created by the personal contact of the managment with other operating men in local organizations of this nature. The greatest single factor in the successful operation of railways after a thoroughly efficient operating organization has been effected, is a comprehensive knowledge of how other operating railway companies are succeeding or failing in dealing with the public in general and with municipal and state authorities in particular, as well as with their employees. A solid constructive program presented by a large group of railways in a given section of the country unquestionably will carry more conviction than the ideas of a similar number of individuals with conflicting views and varying demands.

In addition to this, there are numerous other ways by which the average overworked manager may be greatly helped through personal contact with men from all departments of other railways at local meetings, such as methods of selecting employees and the development of subordinate officers, and the establishment of proper instruction systems, which embody the essentials of man building, as well as a study of methods of correcting social unrest, as far as it may be possible for anyone to contribute.

In all railway companies the process of building men to fill the many diversified positions of railway operation necessitates simple, thorough instruction methods by a competent instructor possessing full knowledge of local circumstances, types and classes of men to be instructed, which vary according to the locality of operation. Results from this source are positive but slow in manifestation and great care should, therefore, be exercised to provide the same advantages for all departments to assure an evenly developed organization.

Accurate enumeration of the many benefits derived from instructions of this nature is very difficult and frequently the only reward for continuation is the positive knowledge that a cheerful, loyal, educated, clear thinking employee is a dependable asset to railway operation, efficiently performing regular duties and generally displaying exceptional discretion in emergencies.

Preliminary investigations of meeting or instruction methods should thoroughly consider the division of contributed time for them; and before final adoption of a system the contributed time should be divided proportionately to the advantages of men and company, as many past failures have been registered when the men were called upon to contribute their own time exclusively for this purpose.

It should be clearly understood that systems and plans of this nature are not confined to the large properties, as many small properties offer glowing examples of what may be accomplished. Their problems are solved

by the general meeting plan, holding bi-weekly meetings for all employees, with an afternoon and evening session to accommodate day and night shifts. The enthusiasm at meetings of this nature is probably greater than that of any single meeting on the larger properties, and it seems advisable for the larger properties to include the general meeting plan in their present meeting arrangement.

The importance of organization development has been fully recognized by many conservative Central Western managements, who have provided in their several state associations for an annual operating men's meeting to be devoted to the exclusive discussion of operating and maintenance problems. Meetings of this character will promote the exchange of ideas, inspection of neighbors' property and methods with a general discussion of the subjects, assisting the delegates in the solution of their individual problems, and in the adoption of new methods, with a collective concentrated effort to overcome objectionable conditions of the locality in which they operate.

An interlocking arrangement of this nature will link the state organization with the many local organizations and generally improve the physical condition of the member properties, with improved service to the general public and, it is to be hoped, increased return to the employee and investor.

THE JOURNAL QUESTION BOX

OUR subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. The topics should be of general interest; information involving the specific design of individual pieces of apparatus is not supplied. Care should be used to include all data necessary for an intelligent answer.

A PERSONAL reply is mailed to each questioner enclosing a stamped, self addressed envelope as soon as the necessary information can be obtained. Anonymous questions cannot be considered. As each question is answered by an expert on the subject involved, and checked by at least two others, a reasonable length of time should be allowed before expecting an answer.

1807—WATER WHEEL GOVERNOR—I was called to a job on a water wheel driven generator which was giving trouble. Here is what I found. It was an Imperial Elec. Co. generator 1200 r.p.m., 15 kw, 120 volts, direct connected to a Pelton water wheel with a flywheel of amout 400 to 500 lbs., governed by a D. O. James governor, driven by a 1/3 hp Westinghouse motor controlled by a G. E. Co. type T. S. 130, Form B. 7 contact making voltmeter. The water pressure is about 190 lbs. When the generator has a load of 30 amperes or over, everything seems to work all right but under that load the governor does not control the voltage, that is, when the governor is closing the needle valve, after the governor stops, the flywheel carries the voltage about 10-12 volts lower and the same thing happens when the governor is opening the valve, as the contacts are set for a variation of about 5 to 6 volts, it makes a swing of about 25 to 30 volts and as the load is all lights you can readily see that this is objectionable. What do you think is the trouble, too heavy a flywheel or a too slow working governor? Would you suggest connecting a resistance of some kind across the line to take say 30 amperes so arranged that when the real load comes on this could be discontinued? W.F.P. (N.Y.)

Probably the trouble is due both to the weight of the flywheel being high and the governor working too slow. If, however, the governor is made quicker acting, hunting may occur. In addition to the suggestion made, we can think of two other possible remedies, but the question as to which is better depends chiefly on the cost of the necessary changes. The remedies are:—(1) Convert the governor, which is now evidently a variable speed governor (speed regulated to keep voltage constant) into a constant speed governor and put a voltage regulator on the direct-current generator. (2) Purchase a 60 cell storage battery and connect it in parallel with direct-current generator. At light load, when the voltage of the generator is high, the battery will charge, and at heavy loads it will discharge. This will help to steady the load. The solution of the problem largely depends on the details of the governor with which we are not familiar but we trust that above ideas may be of assistance. H.W.S.

1808—RECONNECTING 500 VOLT MOTOR FOR 125 VOLTS—A 20 hp, 500 volt direct-current shunt motor was changed to operate on 125 volts. The armature was wave wound and the commutator had an odd number of bars. The following changes were made: The field coils were connected in parallel instead of series so as to impress 125 volts across each as before. The commutator segments were reduced to one half the former amount by pulling out every other mica so as to have each segment of double the thickness, having to add one segment (half of one of the new ones) so as to have an even number of them. The segment added was equivalent to about the thickness of the mica taken out. Same armature coils were used, only doubling their carrying capacity by reducing the former coil turns to one half; the armature was reconnected series-four-pole. The brushes had to be widened from 5/8 to 7/8", I mean, the thickness increased. The motor operates fairly well, the speed having been about doubled. Has this procedure being correctly thought out and how have the electrical characteristics of the motor being changed? A.O.U. (MEXICO)

Paralleling all the shunt coils in changing from 500 to 125 volts was the correct procedure. In either case then the volts per coil would be 125, the current in each coil would be unchanged, and the magnetic conditions would be unchanged. If the armature was not changed and the fields were changed as above, the motor would run at 1/4 the original speed, since the voltage was quartered. For the same armature current the horse-power would be quartered, but the torque would be unchanged. If any larger horsepower is wanted the armature must be changed to carry larger current and to run faster. From the question, we understand that this armature was originally wave (sometimes called series, or two circuit) wound, having an odd number of commutator bars. The mica was taken from between every other bar, and a single bar was added, giving half as many double bars as there were single ones. The coils originally started at one bar, went to a bar on the opposite side of the armature and then back to a bar adjacent to the first one. When the mica was removed half of these coils would be short circuited, since the bars touch. It is understood that the coils were reconnected to avoid this in such a way that there will be two of the old coils in parallel from each double bar to the next. Since there are two coils in parallel always, there is now only half the turns in series on the armature that there were originally. It seems that the armature coils were opened and the coil cut, and then reconnected in such a way as to get on half as many turns per coil as originally, with doubled current carrying capacity. Evidently the turns were halved and reconnected in parallel instead of series, as originally. This would again halve the number of turns in series on the armature, giving one quarter as many turns as originally. The armature was wave wound again when reconnected. This armature, then, should run at the original speed when 125 volts is impressed. We could make no definite comments on this armature procedure without knowing the numbers of bars, slots, and turns per bar. In this case, since the operation was satisfactory, evidently the procedure was all right. In the majority of cases the results would be unsatisfactory because some of the changes are very difficult to make, and because in but few armatures are the numbers of bars, slots, and turns per bar such that these changes are possible. Usually a better method would be to rewind the armature, using larger wire and fewer turns per bar. There must be some other change to the arma-

ture than those given, for they would cause the speed finally to be the same as originally, while the question states it was doubled. Reconnecting as a lap winding instead of a wave winding as stated would give this result. No mention is made of the amount of load put on after the change. To keep the heating of brushes and commutator, and the commutation good the current should not be increased at a greater rate than the brush contact area. Also the brush thickness could not be increased more than from ⅝ inch to ⅞ inch and keep good commutation. The original rated current on 125 volts will only give 5 hp. Increasing to ⅞ inch brushes would permit 7 hp to be used. The changed armature would probably stand four times rated current or enough to give 20 hp but the commutation limits the amount. Doubling the number of brushes (if possible) and using ⅞ inch brush would give a limit of 14 hp. Since nothing was said of commutating coils this was assumed to be a non-commutating pole motor. M.S.H.

1809—CHOKE COILS FOR LIGHTNING—We have considerable trouble with lightning on our 440 and 2200 volt alternating-current lines and 600 volt direct-current lines. We use arresters having spark gaps and resistances but do not find them of much help. We have considered installing choke coils but as some of our lines carry several thousand amperes the expense is large. We have noticed that where our lines enter buildings through iron conduit there is practically no trouble but when they enter through porcelain tubes we are constantly in trouble. We gather from this that the iron pipe acts as a choke coil and we are planning to make all our entrances through iron conduit. Will you please give your opinion on this matter. B.C. (N.H.)

It is a well known fact that iron conduit does have a choking effect on incoming surges. On low frequencies this choking effect is very slight, but this effect is very much increased on high frequencies, such as obtained on lightning discharges. The inductance of this conduit is small and not at all comparable with that of the ordinary choke coil, but its effectiveness is much increased by the eddy current and hysteresis losses of the iron. If you have obtained the desired protection from this conduit, even though its choking effect is not very great, it would be desirable to use it. G.C.D.

1810—CONDENSER IN SERIES WITH TRANSFORMER—What is your opinion regarding the use of a condenser in series with the high side of small transformers—to prevent them burning out when direct-current is switched over temporary emergency. This question comes up from burning up three bell transformers twice in the past six months due to the direct-current being switched on while repairs were being made in the alternating-current service—some were burglar alarms and were dead several days. We have a double-throw switch alternating-current on one side, direct-current on the other side. This is a very large building, a block both directions and nine floors, so you see when we are told the transformers should be disconnected it sounds foolish to us, we have bigger things to look after at these times. Using a bell transformer intended to operate a five inch alternating current bell, I placed three condensers, $\frac{3}{16}$ thick, 1½ wide, 3½ long in multiple, but all in series with the transformer. With a buzzer on the low side no difference in sound could be detected with or without condensers.

With one condenser—the buzzer would not work.

With two condensers—the buzzer worked fair.

With three condensers—the buzzer worked well

With four condensers—the buzzer worked no better

This idea was suggested from bridging magnetos and extensions to alternating-current bells using a condenser to prevent talk current going through ringing circuit of phones. I mentioned my idea to two electrical engineers, one said it would not work, the other did not know. Possibly owing to the condenser causing a leading current — more current passes through the transformer than safety or economy would warrant. Three ampere plug fuses did not protect the transformer from burning out when the direct-current was switched on as mentioned. We burnt out some fan motors too, which were in out-of-way places, a few left on during winter in warm places. Probably a condenser in circuit with the small fans would be practical. I have saved enough tinfoil off tape to make a number of condensers and as the tension is low no impregnating would be necessary. J.E.M. (MICH.)

Condensers in series in the high voltage side of small transformers should operate satisfactorily providing the voltage developed across the condenser is not too great when carrying the maximum load. This voltage can be calculated as follows:—

$$E = \frac{I}{2\pi f C}$$

Where
I = load current in amperes.
f = frequency of supply, cycles per second.
C = capacitance of condensers in farads.
π = 3.1416.

The limit for this voltage cannot be stated definitely but should not in general exceed 20 to 25 percent of normal supply voltage. J.F.P.

1811—POWER-FACTOR CORRECTION WITH ROTARY CONVERTER—Just what effect does a 5 to 7 percent reduction in voltage have on the power-factor corrective effect of a three-phase rotary converter. Is it commercially possible to maintain 95-100 percent power-factor on a converter used for coal mining work where the loads vary from 20 to 60 percent of full load without a likelihood of damage to windings due to excessive heating? F.G.F. (W.VA.)

See article on "Synchronous Motor Operation", Aug. 1917, p. 313; also "Power-Factor Correction by Rotary Converters", Feb. 1912, p. 150; also "Power-Factor Limitations of Rotary Converters", Sept. 1913, p. 882. If a converter is operating with its field excitation adjusted to give unity power-factor and has its applied voltage reduced, it will be over-excited and will, therefore, cause the power-factor of the line to be leading. The amount of this change in power factor, for a given change in voltage, depends largely on the saturation in the magnetic circuits. If the machine is already over-excited, so as to correct for lagging power-factor in the line, the corrective effect will be increased by the reduction in voltage; while, if the machine is under-excited, so as to correct for leading power-factor in the line, its corrective effect will be decreased by the reduction in voltage. A machine of normal design proportions operating at unity power-factor, full load, will change to about 97 or 98 percent power-factor, leading, when the applied voltage is reduced 7 percent; and, when operating at 95 percent power-factor leading, will change to about 91 or 92 percent, when the voltage is reduced 7 percent. It would hardly be possible to maintain the power-factor on a compound-wound machine any better than the value of 95 to 100 percent, as given above, on a load variation of 20 to 60 percent, without regulating the shunt field. This will depend largely on the strength of the series field. By adjusting the shunt field so as to give unity or slightly leading power-factor at the high load, the heating at the lighter loads due to the decreased power-factor, should not be injurious. M.W.S.

1812—STARTING ROTARY CONVERTER—In starting an 1100 kw, synchronous rotary converter from a 600 volt bus, direct-current, in what states are the shunt and series field in relation to one another? H.MC. (N.J.)

Under normal operating conditions, the magnetizing force of the series field adds to that of the shunt field. However, when the machine is being started from the direct-current side (with the field windings connected as before) the direction of the currents in the series and shunt windings are such that the series field bucks the shunt field. Then, to get a greater starting torque, or, in other words, to start the machine with a smaller current, the series field should be short-circuited, or preferably reversed, during starting. However, the current required on starting is so small (usually not more than 10 or 15 percent of full load) that the bucking effect of the series field hardly warrants the extra switching equipment required to short-circuit or reverse the series field. M.W.S.

1813—DUDLEY ARTICLE—In your December, 1917 issue, bottom of p. 508, Mr. Dudley says that the no-load current of an induction motor should be between 20 and 40 percent of full-load current. I find that this statement is true when it is applied to motors with squirrel cage rotors, but far from accurate for wound-rotor motors. Why should the currents be different and what is the true ratio for the wound rotor motor current? J.H.B. (WYO.)

It should be noted that the magnetizing current will vary between the limits of 20 and 40 percent of full-load current only on squirrel-cage motors which have a continuous rating and which do not have more than 12 or 14 poles. If the motor has a greater number of poles or is designed for a high-torque short-time rating, the magnetizing current will exceed these values and under extreme conditions may be as high as 90 percent of full-load current. The winding in a wound rotor is usually wound through the top of the slot while a squirrel cage bar is put in from one end. This makes

the opening of a wound rotor slot wider than a squirrel cage rotor slot and has the effect of a longer air-gap which increases the magnetizing current. For this reason, wound rotor motors will have approximately 15 to 20 percent more magnetizing current than the corresponding squirrel cage motor.

C.W.K

1814—Pounds-Feet Torque It always seems to me that torque in pounds-feet is about as meaningless and as confusing as poundals, etc. and that torque in synchronous watts would be better, since poles and frequency would not need to be known. I have seen test sheets where frequency was forgotten and poles could not be determined. What would the formula be for torque in synchronous watts? Also for added resistance in a phase-wound motor? L.P.R. (ONTARIO)

By definition, the torque in synchronous watts is the power that would be delivered by a given torque in pound-feet, operating at synchronous speed. This application is general and may be applied to A-C. or D-C. machinery. However, synchronous speed must be the speed at which the impressed e.m.f. exactly equals the counter e.m.f., and no current flows through the armature circuit.

Torque in synchronous watts = 1.42 × *synchronous speed* × *torque in lb.-ft.*

For an induction motor the synchronous speed is determined by the frequency and number of poles, so the formula reduces to:—

Torque in syn. watts = 171 × $\frac{f}{p}$ × *torque in lb.-ft.*

Torque in synchronous watts may also be expressed:—

$$\textit{Torque in syn. watts} = \frac{\%\ \textit{Slip}}{\textit{Rotor } I^2R}$$

When resistance is added to the circuit of a wound rotor the I²R loss, at any given torque in pound-feet, is directly increased. However, the slip is also proportionally increased so there will be no change in the torque in synchronous watts.

Where torque in synchronous watts is known, torque in pound-feet may be determined as follows:—

Torque in pound-feet = 0.0587 × $\frac{p}{f}$ × *torque in syn. watts.*

It will be noted that the above formulae require that the synchronous speed, poles and frequency, and torque in pound-feet be known, therefore, has no advantage over the value of torque in pound-feet. Rotor I²R loss is very difficult to obtain so the second formula is of no practical value. Torque in pound-feet is in general use and is the fundamental conception of the forces exerted on a conductor in a magnetic field and carrying a current. The term "torque" is an expression of force and is independent of motion. H.L.S.

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

OCTOBER 1919

Does it Pay to Dip and Bake Armatures?

THIS QUESTION was recently asked one of the operating officials of a large holding company, controlling a number of street railway properties in some of the larger size cities throughout the New England states. An affirmative reply was given, and the following data presented as evidence to confirm their belief that it does pay to dip and bake armatures.

NUMBER OF ARMATURE FAILURES

	Months	City A	City B	City C
1918	June	157	95	37
	July	150	77	59
	August	219	108	56
	September	110	64	44
	October	83	37	60
	November	55	25	30
	December	46	25	18
1919	January	35	8	17
	February	20	16	12
	March	19	16	21
	April	26	17	13
	May	34	27	15
	June	42	27	4
	July	25	19	5

City	Population	Equipments Operated
A	130 000	80 Quadruple and 78 Double Equipments
B	100 000	70 Quadruple and 62 Double Equipments
C	75 000	74 Quadruple Equipments

The above figures were taken from the weekly report of all mechanical and electrical armature failures of the various indicated city properties. These weekly records were combined under months, all of which include four weekly reports, except August and November 1918, and March and May of 1919, which includes five weekly reports. On these properties, systematic dipping and baking was started in July 1918.

The curves shown in Fig. 1 have a decided upward trend during the month of August 1918, which is partly due to the fact that this month contains five weekly reports. A further possible explanation for this might be the operation of a large number of extra open cars put in service during the summer months. After this month, there is a continuous drop, which the operators seem satisfied is due largely to the dipping and baking of their armatures. Whether this treatment of dipping and baking would show itself so effectively in so short a time, is a debatable question, and would depend upon how soon all the armatures were treated, the weather, and local service conditions.

In general, on most street railway properties, the total armature failures are sub-divided as follows:—mechanical 75 percent and electrical 25 percent; however, on these properties, they report a reverse condition, or 25 percent mechanical and 75 percent electrical. This being the case, when dipping and baking was started, the electrical failures were immediately cut down and resulted in such a remarkably good showing.

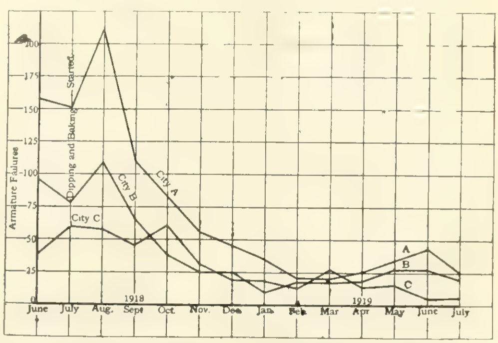

FIG. 1—EFFECT OF DIPPING AND BAKING ON ARMATURE FAILURES IN THREE NEW ENGLAND CITIES

The procedure followed in dipping and baking armatures on these properties is:—

1—Heat the armatures about 10 hours at 100 degrees C.

2—Dip in a high grade baking varnish, with the pinion end down to keep the commutator from getting covered with the varnish.

3—Drain off the excess varnish while the armature is in a vertical position.

4—Bake at 110 degrees C. for from 25 to 30 hours.

J. S. Dean.

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OCTOBER 1919

Lubrication of Control Apparatus

In the application of mechanical movements to obtain various functionings where hinged or sliding action are required, friction is sure to occur. In some cases the friction is a hindrance and in others a help in obtaining the required result. Practically all control apparatus, whether of the pneumatic switch, magnetic contactor, drum type or a combination of drum and contactor, have both the good and the bad qualities of friction.

LOSS OCCASIONED BY FRICTION

An inherent characteristic of friction is loss of power due to heat. When designing apparatus of any form, whether for railway or other uses, it is the aim of the engineer to eliminate as far as possible all detrimental friction for this cause. Heating other than that brought about by I^2R losses being the direct outcome of friction, indicates the binding of parts and results in sluggish action of the moving details.

INJURIOUS FRICTION

Practically all friction can be classed as injurious and wasteful, inasmuch as it indicates wearing of parts, depreciation of the machine as a whole and loss of power. The action of either electropneumatic or electromagnetic power interrupting switches, in which speed of opening is very essential, may be impaired to a considerable extent by undue friction. This is especially true of those switches whose operating energy decreases rapidly with drop in line voltage.

All moving parts employing hinge pins, roller or sliding action to accomplish a given purpose, include injurious friction in various degrees, which causes a waste of both material and energy. In the pneumatic switch itself, this friction is obtained in both the hinge and sliding form, while in the magnetic type only the hinge friction is found. However, any disadvantage obtained by the sliding friction of the pneumatic switch is overbalanced by the greater pressure at the contact jaws. With the drum type of controllers, only the hinge form of injurious friction is obtained, which occurs at the bearings of the drum shafts.

USEFUL FRICTION

There are certain cases where friction is a help rather than a hindrance in obtaining definite results from particular designs of apparatus. With practically all types of switches, whether of the electropneumatic, electromagnetic, drum type and even the ordinary knife switch, the friction obtained in operation is used to a considerable advantage. In these instances the friction supplies a wiping action on the current-carrying parts, insuring a bright clean contact surface. The elimination of pits is particularly advantageous, as it prevents the occurrence of hot spots due to poor contact. Corrosion of contact surfaces exposed to gases is also overcome. The amount of wiping action obtained is usually limited to the amount of power available for operating the switching device, and a proper balance between the amount of wear and clean contact surface required. Considering the case of the drum-type controller, however, it should be understood that with the advantage of clean contact surface, the disadvantage of undue wear of the contact plates may also be obtained. The cause of this is easily recognized as friction is directly proportional to pressure, the pressure being obtained with heavy finger springs and close adjustment. Interlock contacts may be cited as another example of useful friction, as the pressure between the fingers and the plate is usually low and the voltages not very high. A dirty contact under these conditions would be likely to give trouble were it not for the wiping friction.

OILING OF PARTS HAVING USEFUL FRICTION

As a general rule, no great amount of attention need be paid to lubrication of parts employing useful friction, if heavy arcing duty is obtained, as the heat of the arcs would very soon destroy any lubricating qualities of the lubricant used.

For such parts as reverser drums, and *K* controllers, where the arcing, if any, is usually small, or very infrequent, considerable pains should be taken to keep all wearing parts well lubricated. The lubricant in these cases should be vaseline, which should not be spread on too thickly, as it is only a waste of material and creates dust and dirt-collecting spots.

With such apparatus as reverser drums, the use of too much lubrication causes a decrease of creepage insulation surfaces, due to the copper dust and dirt retained by the vaseline. Low voltage control circuits, whether on drums or on interlocks, require thin oil instead of vaseline.

In the case of *K* controllers and other drum apparatus, some advancement has been made in the continuous oiling of contacts by means of pockets in the back of the contacts containing an oil soaked wick or felt. A hole is drilled through the contact to the pocket. The bad feature of this method is called to attention by the fact that the holes very often become clogged and the lubricant ceases to function. Frequent inspection, however, will take care of this trouble. A free flowing oil should be used for saturating the wick or felt. For the interlock contacts a slight amount of vaseline may be put on in a thin coat.

OILING OF PARTS HAVING USELESS FRICTION

All parts of control apparatus, such as hinge pins, bearings as encountered in drum controllers, and wearing surfaces, other than arcing tips should, under all conditions, be kept oiled to prolong their life. The hinge pins, however, having a bearing of brass or copper on steel have been known to run for years without appreciable wear and little oil. The sliding bearings, however, give greater satisfaction if kept well oiled and free from dirt. In oiling all such parts as hinge pins, sliding bearings and even roller bearings, a light grade of machine oil should be used. It is unnecessary to recommend any particular oil for this part of the apparatus, as there are several good, well known grades on the market.

OILING OF CYLINDERS

Practically all air-operating cylinders giving satisfactory service have their pistons equipped with some form of piston leathers. To keep the pistons working freely in the cylinder it is necessary that proper attention be paid to lubrication, or sluggish action will most certainly occur, especially on low air pressures.

After several years experience with pneumatic cylinders, it has been found that piston leathers require a special grade of oil to give them long life and smooth operation under practically all conditions of weather. With some oils the leathers soon rot away. Other oils flow freely in warm weather and gum up in cold weather. Profiting by past experience, a special grade of oil has been obtained which is known as *HL* oil for cylinders employing piston leathers. The use of the wrong kind of oil cannot be too strongly condemned, as the results obtained from their use are rather trying and expensive.

Piston leathers are made in the form of a cup and are treated with a softening compound. Should they be neglected in service, they soon dry out and crack, giving rise to leaky pistons. Oiling should take place about every 2000 miles for interurban equipments and every 1500 miles for city cars. Only a small amount of oil should be used, as an excessive amount soon clogs the valves.

TIME OF OILING

a—Switch Parts—With inspection based on a 2000 mile period, all switch parts should receive attention about every fourth inspection.

b—Drums and Interlocks—The condition of interlocks, reverse drums and *K* controller drums should be noted at every inspection and lubricant added as required.

c—Switch Cylinders and Drum Cylinders—The necessity for oiling piston leathers will become very apparent should it be neglected for any length of time. Switches will become sluggish and leathers leaky. A small amount of *HL* oil should be injected into the cylinders about once a month and oftener if the action of the switches indicates the need.

H. R. Meyer.

THE ELECTRIC JOURNAL

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The Function of the Load Dispatcher

Centralized control of the operation of central station systems becomes essential as soon as two or more power plants are to be operated in parallel or the transmission network makes it possible to feed substations over two or more routes. Accordingly, the office of load dispatcher or system operator has been established in nearly all large power systems for the purpose of providing a directing head for the operation of the generating and transmission system.

The function of the load dispatcher is to provide a supply of power—adequate in quantity and satisfactory in quality—to meet the requirements of all consumers connected to the system. The chief advantages to be gained through the establishment of a load dispatching office are: first, improvement in continuity and quality of service; and second, economy of operation. Having the resources of the entire system at his command, the load dispatcher will plan the grouping of the lines and stations so as to protect all service to the greatest degree possible. When interruptions do occur, by his close touch with all stations, he is able to restore service in the minimum possible time. He is further able to supervise the system frequency, and to correct any unworkable voltage by a re-arrangement of the loading and grouping of the lines. He thus becomes a very important factor in maintaining the high standards of service now set by central station systems.

Through his centralized control of operations, the load dispatcher is also able to schedule the power generating machinery at the various stations so as to attain the maximum economy of production. He is further able to divide the load properly, so as to get the maximum possible service from the transmission lines available. Thus he becomes an important agent, not only in reducing the power costs, but also in reducing the investment required in the transmission system. In a word, through the activities of the load dispatcher, important improvements in quality of service are attained and the cost of power is reduced.

The equipment for performing this work, consists fundamentally of special communicating equipment by which the dispatcher can keep in constant touch with all parts of the system; and of suitable diagrams and charts by which he may know the load being carried, generating capacity in use, position of switches, etc. Ideally, the diagram would be a complete chart of the entire system, directly connected to the actual equipment, so as to record automatically the loads carried at all stations and the operation of all switches. In practice such a system is impracticable. In many instances, however, the ideal has been partially obtained by making some of the more important switches record their operations automatically. Where the indications on the diagram as to open or closed switches, etc., are made by hand, a rigid discipline for the dispatcher handling the system is necessary, for unless all changes are promptly recorded, the diagram becomes inaccurate and loses most of its value.

The load dispatching system of the Philadelphia Electric Company, described in this issue, is one of the most complete in existence. The signal lights, being controlled from a keyboard at the dispatcher's desk, can be conveniently operated immediately on receipt of telephone notification, an arrangement as near to the ideal of purely automatic operation as can reasonably be attained in practice. The "section unit" of panels is also a very desirable feature, since it provides the flexibility and room for growth which is so essential to any rapidly growing central station system. E. C. STONE

Industrial Adaptation in the War

A prominent business man said some months ago that the outstanding contribution America made to the winning of the war was the mobilization of her industries. Our industrial resources were feared by Germany even before we entered the war, but their contribution to the Allied cause before April 1917 was but feeble compared to that after we came in and all our industrial establishments had but one ultimate object—"To Win the War".

So far as possible each organization undertook the task nearest in line with its normal activities. Shells and grenades were turned out by those who had the mechanical equipment, and particularly the organization for it. The same was true of airplane supplies and the thousand other requirements of modern warfare.

Soon after our country entered the war an appeal came to the Westinghouse Company to provide facilities for spinning and destructive tests of airplane propellers. Spinning speeds from zero to 2500 r.p.m. were provided for, with facilities for measuring the power taken and the deflections of the propeller blades. A total of over 150 separate test runs were made, many of them driving the propeller to destruction. These tests were made for both the Army and Navy aviation organizations and covered a period from November 1917 to December 1918. The evidence disclosed by these tests showed the desirability of propellers better adapted to withstand abrasion, heat and moisture.

The description given in this issue by Mr. N. S. Clay of a type of propeller developed during these tests and in response to this need is an example of the special effort put forth by American industry on lines more or less alien to its normal activities, in order that no possible assistance to our fighters across the sea should be left unsupplied. R. P. JACKSON

Load Dispatching System

Of the Philadelphia Electric Company

George P. Roux
Engineer,
The Philadelphia Electric Company

THE PHILADELPHIA Electric Company system includes that of the Philadelphia Electric Company, serving all the territory within the city limits of Philadelphia; the Bala & Merion Electric Company, serving several suburbs in Montgomery County; and the Delaware County Electric Company serving Chester and most of Delaware County to the southwest of Philadelphia. Directly and indirectly through other utilities, the Philadelphia Electric Company's system supplies light and power to a territory 40 miles long, extending along the Western shore of the Delaware River from Bristol, on the north, to the Delaware state line, on the south.

A total of approximately 360 000 kw combined light and power connected load is supplied throughout this territory from nine steam generating stations, having an aggregate generating capacity of 240 000 kw. For the distribution of the load, 356 miles of transmission lines at 6600, 13 200, and 66 000 volts are in use, together with 27 company substations and 30 industrial substations.

FIG. 1 GENERAL VIEW OF LOAD DISPATCHER'S ROOM

The Schuylkill stations No. 1 and No. 2 (140 000 kw) in Philadelphia and the new Chester station (60 000 kw now and having an ultimate capacity of 120 000 kw) are connected through a 66 000 volt double-circuit steel tower transmission line, which acts both as a tie line and feeder line, supplying the most important shipyard and industrial plants along the Delaware River. The Delaware station, on which work has been started, is located in the proximity of the central section of Philadelphia on the Delaware River. When completed, it will have a capacity of 180 000 kw.

The system of generating plants, substations, and feeders is shown in Fig. 2. Part of the load supplied from this system is that required by the electrification of the Pennsylvania Railroad and part of the requirements of the Philadelphia Rapid Transit Company, as well as some other traction systems and utilities.

LOAD DISPATCHING

The load control of any electric light and power utility requires the co-ordination of the complicated functions of production, transmission, and transformation of the electrical energy to meet at all times the requirements of the service, and above all to insure a continuous and adequate supply throughout the entire system to all customers. It is obvious that where the load control of a system is distributed among a number of supervisors, confusion in the operation, delays in the service, misinterpretation of orders and conflicting and sometimes dangerous moves are to be expected from the operators, whereas a central control, with close and comprehensive supervision of this important part of the service, insures operation with a maximum of safety and efficiency.

The nature of the service rendered to the public admits of no delays, and no failure. Power must be available at any and all times, as required by the customers, without warning or notice prior to its use, and the public utility must hold itself ready to render the service every minute, day or night.

The service must be rendered instantly from the generating source to the customer's premises with no delay in transit. The kilowatt-hours of modern practice cannot be stored or loaded on a car and placed on a siding, awaiting shipment to a customer, like other merchandise or commodities. The performance is continuous from producer to user, both being intimately and directly connected by the intervening system of transformation and distribution through which the electrical energy is delivered.

The planning work of the electrical load dispatcher requires the most thoughtful and careful consideration in every one of its minute details, together with a perfect knowledge and acquaintance with the operating personnel; with the equipment of the system and its conditions, capacity and performance characteristics,

and in addition a clear vision of the load requirements of the system. Weather conditions, industrial, commercial, civic and social activities are all elements which enter into the daily problems confronting the load dispatcher, and the intricacies of the office are often complicated by emergencies arising from unexpected demands, system or customer troubles and failures, all of which require prompt solution, good judgment, a cool head and judicious treatment. It is therefore of prime importance that the load dispatcher have at his command a system and method by which the performance of his duties can be carried out effectively and with full security.

Different methods of load dispatching have been used in the past by the Philadelphia Electric Company, until the growth of the system made necessary the formulation of a comprehensive and adequate system, having sufficient flexibility to be amenable to subsequent changes or increases of load, and further expansion of the system in general; while at the same time offering additional guarantees of reliability, simplicity and speed of operation.

To that end, instead of the conventional wall maps or line diagrams, a sectional unit system of panels similar to a central station switchboard was adopted, the condition of each piece of apparatus or switch to be controlled being indicated by lights or plugs according to a definite schedule.

This board, shown in Fig. 1, is located in the load dispatcher's room at the main office building of the company at 10th and Chestnut Streets. It consists of 105 steel panels, each 11 by 16 in. and one eighth in. thick, finished in dull, dark green, baked-on enamel, the line diagrams and markings being of white celluloid cemented on the panel. Spare panels are left for future additions.

The panels are mounted on a steel frame work with a wooden framing front and sides of mahogany finish, including a top cornice and a sub-base 28 in. high, projecting 16 in. in front of the board, and covered with green linoleum, so as to permit of reaching any part of the upper panels when necessary. Inside of the sub-base are located the contact boards and fuses controlling the indicating lamps of the panels.

The board is crescent shaped, being 20 ft. long and 10 ft. high from the floor line. It allows for future extension to double its present capacity, and will ultimately have a semi-circular form, giving a full and uniform view of the entire board to the load dispatcher and operators sitting in the center at the control desk. Full access to the front and rear of the board is thus obtained for its operation and maintenance, as illustrated in Fig. 4.

Each station has its separate panel or set of panels, which are arranged both geographically and according to the class of service supplied. The generating station panels are located at the lower end, then the intervening substations or switching devices and finally, near the top, the industrial or large customer substation panels.

On each panel all the apparatus of importance to load dispatching is neatly indicated in accordance with a standard and simple legend of symbols; a circle for rotating apparatus, a square for a transformer, a circle and square for rotating apparatus connected through a transformer, a rectangle for a turboalternator, etc., as shown in Fig. 6. Each piece of apparatus and panel is plainly numbered and marked. In addition, when the circuit is alive, the indicating lamp of the apparatus is lit. These lamps consist of bull's eyes, fitted with No. 2 U-standard telephone board, 24 volt, incandescent lamps, controlled from the load dispatcher's keyboard, adjoining the telephone exchange. A green cap covers the lamps for normal operation, while a red cap indicates blocked-out equipment.

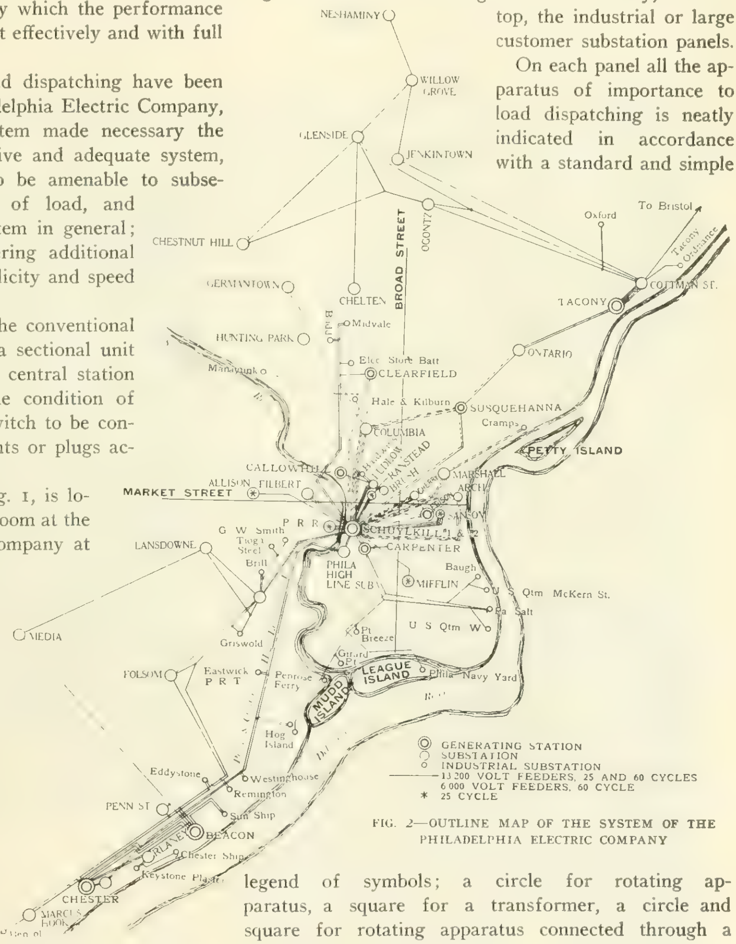


FIG. 2—OUTLINE MAP OF THE SYSTEM OF THE PHILADELPHIA ELECTRIC COMPANY

Oil circuit breakers are represented by a lamp, and air break or line disconnecting switches by plugs with

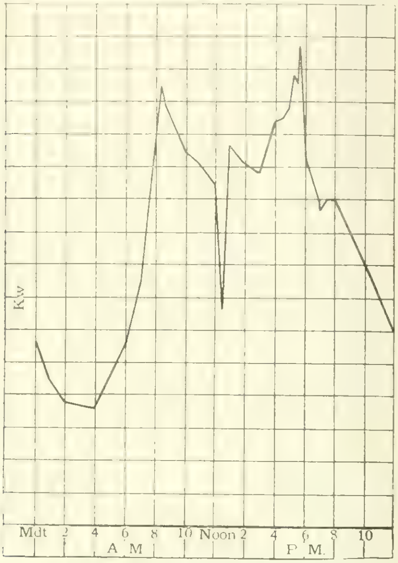


FIG. 3—TYPICAL WINTER DAY LOAD CURVE ON THE PHILADELPHIA ELECTRIC COMPANY SYSTEM
Including both 25 and 60 cycle loads.

different styles of heads and markings, as their operation is not as frequent or as important as that of the oil circuit breakers.

Feeder routes are not shown on the panels because they complicate rather than simplify the map, and are

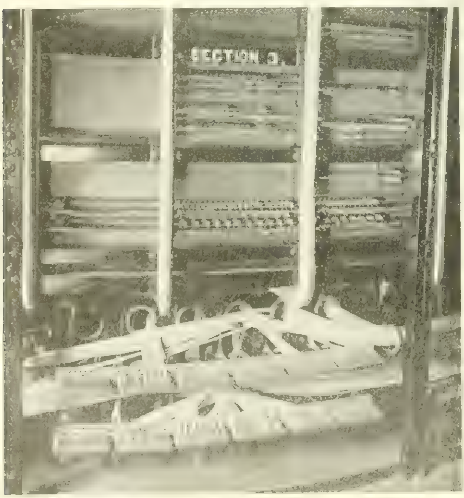


FIG. 4—REAR VIEW OF LOAD DISPATCHER'S BOARD

unnecessary for load dispatching. Any panel can be readily removed and replaced in case of change in its layout or of its relative position in the system when additions, alternations or extensions are made.

The load dispatcher's telephone exchange is located in front of the board, in the center of the crescent so as to give a ten foot radius from the board. The exchange is a three-position, Bell telephone private branch exchange, as shown in Fig. 5. The first and third are the operating positions, with the keyboard controlling the lamps in the form of a panel and wing table between these two positions, and within easy reach of either operator. Each position has two panels, with a total capacity of 160 stations.

The positions are in multiple, and are equipped with "calling" and "busy" pilot lamps. There are 10 cords to the position. Switching keys are provided for cutting the positions in half, giving the exchange four op-

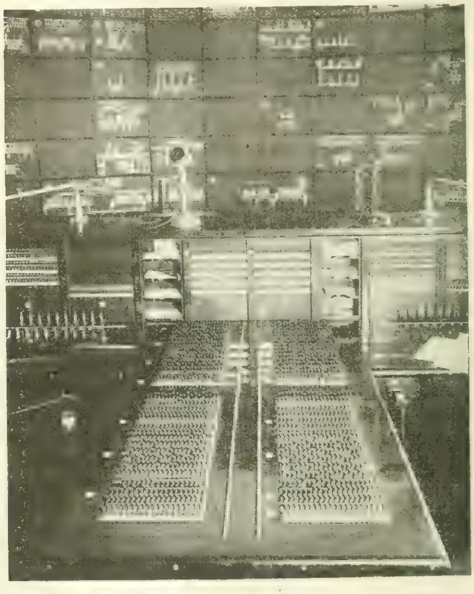


FIG. 5—TELEPHONE AND SIGNAL BOARDS

erating positions. The bracketed transmitter and the headband receiver may be connected to either half of a split position through a two-way jack, from which also a second operator's set may be connected in on the whole position or either half of it.

The exchange is used exclusively for operating purposes. Direct wires connect with the switchboards of all company stations, the largest industrial substations, and the trouble department. Three tie lines go to the Company's regular telephone exchange, and two trunks to central. Telephones, connected to central, are maintained for dispatching purposes in most high-tension consumers' substations.

The vertical section of the keyboard has 100 switches and its horizontal section or wing to the exchange 1420 switches. Each switch is of the pull-

button single-pole type used in standard telephone equipment. There are 800 lamps now in use on the board, 600 of which are normally burning. The current for these lamps is secured from either one of three sources; alternating current from the company circuit; direct current from an Exide 12 cell storage battery; or direct current from a three kilowatt motor-generator set. These sources of supply can also be used for emergency lighting of the load dispatcher's room. The equipment of the load dispatcher's office is completed with a flat top desk, a card index, filing cabinet, dictaphone, typewriter, wardrobe, etc. and also a telautograph connected with the operating engineer's office.

The load dispatcher is responsible at every moment for the generation, transmission and transformation of the proper amount of load. He computes the demand to be met; schedules it on his generating stations; ascertains that each station will have sufficient steam and electrical capacity to carry the load; and that there will be reserve equipment on the system to compensate for the loss of the largest unit running. To do this he must know generally the load required by each substation and each distribution circuit; for which purpose, he maintains an extensive system of records. No switching is done without his direction, except that carried out according to standardized instructions to restore

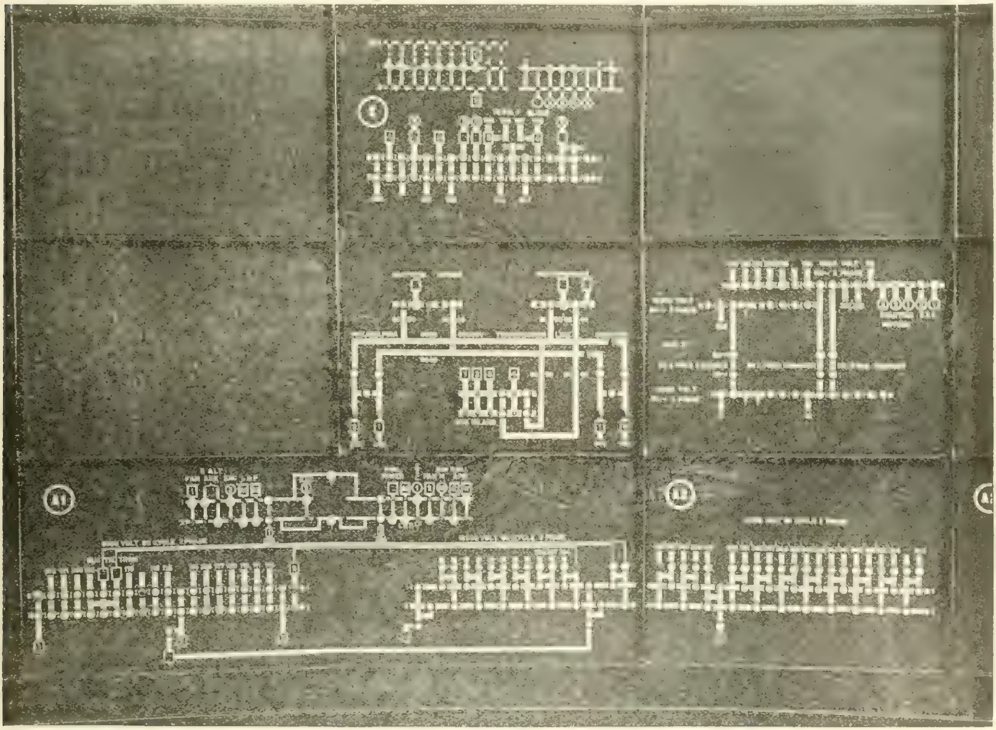


FIG. 6—DETAILED VIEW OF BOARD

service in case of emergency. The load dispatcher is called before any unit is started or stopped. No apparatus is worked on without a permit from him. He is responsible for all blocking, and for the details of switching in connection with the testing of new, or repaired equipment.

OPERATION

The load dispatcher, under the direction of the operating engineer, has full control of the load from its generation (beginning in the boiler room) to the customers' premises. All apparatus affecting the generation, transmission, and transformation of the electric energy are at all times under control of the load dispatcher. The 25 and 60 cycle system of feeders at 13 200, 6600 and 2400 volts, the 66 000 volt transmission system, the direct current 250 volt commercial light and power load and 600 volt railway load, comes under his jurisdiction and even certain customers' load systems, also the lighting system of generation.

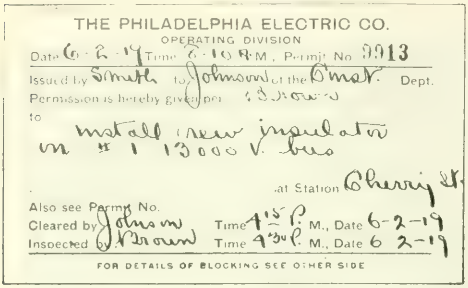
Work Permit—The load dispatcher, when requested, issues permits for the blocking of switches, or to render certain equipment temporarily inactive for the purpose of inspection, repair, maintenance or construction work. These permits are issued on the card shown in Figs. 7 and 8, at times and occasions that will interfere the least with the service, except in emergency

cases. They are made out in duplicate by the load dispatcher and generally issued over the telephone to the requesting party through the station or substation operator who writes up a similar set of cards bearing the number given by the load dispatcher.

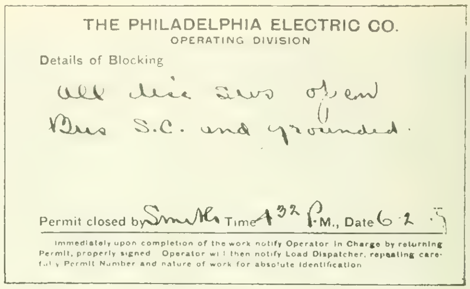
Both the station operator and load dispatcher keep one card on the operating desk until the switch or apparatus is reported cleared. The duplicate card made by the load dispatcher is filed and the duplicate card of the station operator given to the party requesting the blocking, to be returned when the apparatus is cleared.

The load dispatcher takes special care in every case

telephone system, the load dispatcher is constantly in touch with the different places where the load is handled. Reports are made at stated intervals of conditions at the various stations or substations throughout the entire system. A daily record of operation is kept in a log book where the load on each station is entered, also the peak load, interruptions properly classified, and in general all information of interest to the operating department and load dispatching. The chief load dispatcher is assisted by a load dispatcher and an assistant load dispatcher on each shift, three shifts a day, or a total force of seven men.



THE PHILADELPHIA ELECTRIC CO.
OPERATING DIVISION
Date 6-2-19 Time 3.10 P.M., Permit No. 9913
Issued by Smith to Johnson of the Const. Dept.
Permission is hereby given per J. J. Brown
to
install new insulator on #1 13000 V. bus
at Station Cherry St.
Also see Permit No.
Cleared by Johnson Time 4:15 P.M., Date 6-2-19
Inspected by J. Brown Time 4:30 P.M., Date 6-2-19
FOR DETAILS OF BLOCKING SEE OTHER SIDE



THE PHILADELPHIA ELECTRIC CO.
OPERATING DIVISION
Details of Blocking
All disc sws open
Bus S.C. and grounded.
Permit closed by Smith Time 4:32 P.M., Date 6-2-19
Immediately upon completion of the work notify Operator in Charge by returning Permit, properly signed. Operator will then notify Load Dispatcher, repeating carefully Permit Number and nature of work for absolute identification

FIGS. 7 AND 8—FRONT AND REAR VIEWS OF BLOCKING PERMIT

to see that all other switches, valves or apparatus affected by the blocking that has been authorized, are properly handled and disposed of, in order to avoid interference with the dispatching of the load. Red caps are inserted on the indicating lamps of the load dispatcher board for all switches that are blocked and are not removed until they are reported cleared by the station operator.

Through the private exchange and its direct wire connections, or through the Bell or Keystone telephone system in case of emergency or failure of the private

The operation of this system of load dispatching has been most satisfactory. It is clear and comprehensive and affords at every minute a complete, condensed and accurate view of the situation of the whole system. It has greatly improved the efficiency of operation, reliability and quality of the service, especially in time of trouble, permitting the prompt and accurate transmissal and execution of orders, avoiding confusion and delay, thus insuring to the greatest possible extent, continuity of service from the sources of generation to the points of consumption.

Turbine Gear Drive for Torpedo Boat Destroyers

W. B. Flanders
Marine Engineering Dept.,
Westinghouse Electric & Mfg. Company

When it is considered that a 1200 ton destroyer requires propelling machinery of a capacity equal to that put into a 30 000 ton battleship, and that this machinery must be operated by a force of thirty or forty men in the small boat as against 200 in the larger one, some conception will be had of the problems involved in the design of such equipment.

The U. S. S. "Tennessee", an electrically-driven battleship of 28 000 rated shaft horse-power, has two turbines with generators, four motors and a large switchboard. The U. S. S. "Clemson", a turbine gear-driven destroyer of the same rated shaft horse power, has two cross compound turbines with reduction gears. Its principle features are compared with those of the Tennessee in Table I.

The relatively greater power required by the destroyer is due, of course, to its higher speed, the power required increasing approximately as the fourth power of the speed and the two-thirds power of the displacement. As the propeller speed can be increased with the ship speed, the speed of the propelling machinery can also be increased and this accounts in a large measure for the decreased weights in the case of the lighter, faster boat. It being necessary to make even greater

reductions in weight in order to come within the allowable amount and, as the number of men required for the operation must be kept to a minimum, the type of machinery must be of the simplest form possible, consistent with reliability and economy.

Increased rotative speed means decreased size and weight of driving machinery. So having used as high

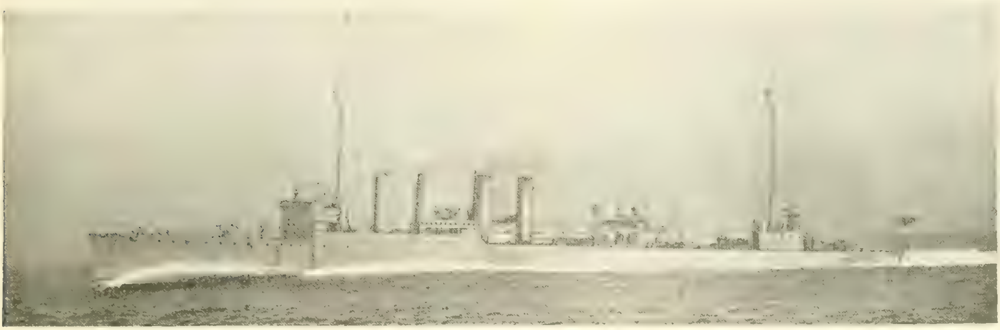


FIG. 1—1200 TON, 35 KNOT, 28 000 HORSE-POWER, UNITED STATES TORPEDO BOAT DESTROYER

a propeller speed as is consistent with good performance, the use of reduction gears allows the main turbines to be again increased in speed with a further gain in weight. Another gain due to the increased speed is in the decreased steam consumption of the main turbines, with the resultant decrease in weight of fuel necessary for a given distance or cruising radius, or

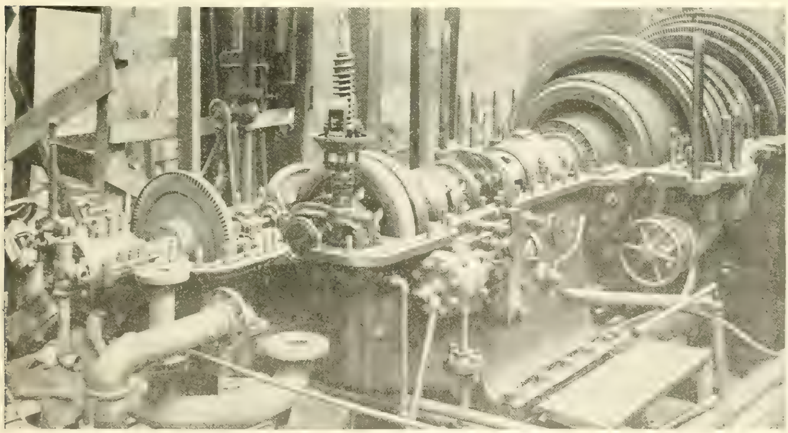


FIG. 2—MAIN AND CRUISING TURBINES

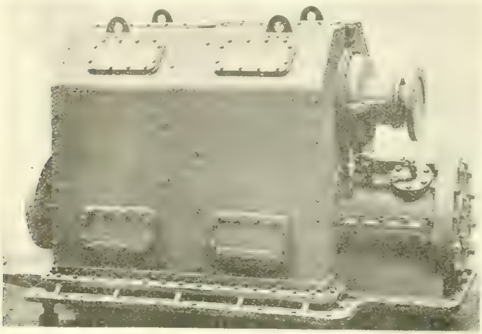
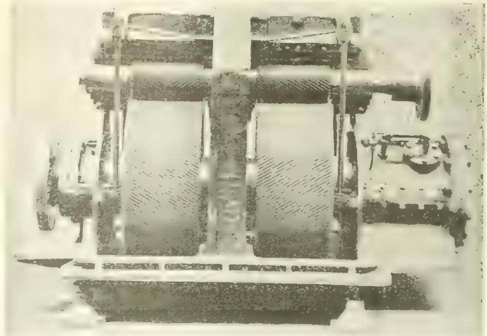
else an increased cruising radius for a given fuel displacement. This cruising radius at the slower speeds, for instance 15 knots, is of great importance and various means are used to keep the steam consumption low at the low speeds. With the high-speed geared turbines, a relatively large number of rows of blades or stages can be used, which tends to give good efficiency at the slower speeds. In addition, a cruising element is employed on the high-pressure portion of the turbine. This element or group of stages is by-passed at the high speeds.

In the destroyers Henley and Mayrant, smaller boats of 750 tons displacement, where the fuel supply is limited, a cruising turbine is used in addition to the cruising element. This is a small, single-wheel re-entry turbine, connected through a reduction gear, by means of a pin-type clutch, to the shaft of the main turbine, Fig. 2. A mechanical synchronizing device enables the operator to connect the cruising turbine without stopping the main turbine.

An interesting point is the wide range of power over which good economy is desired, as shown in Table II. If in this larger boat a cruising turbine had been installed, the consumption at 15 and 12 knots would have been materially lowered; probably to 12.5 and 14.0 lbs. respectively; lack of space prevented their use in the larger boats, however. Fig. 2 also shows one of the main turbines, which is connected through a single pinion gear, Figs. 3 and 4, in these smaller destroyers, where complete expansion units in one cylinder are mounted on each propeller shaft.

The 1200 ton boats of the Clemson type require about double the power of the Henley and Mayrant equipments, and as there are the same number of propeller shafts (two) the turbines were made cross-compound with two pinions on each gear, as indicated in

Fig. 5. The astern wheel is on the low-pressure turbine only, and will develop about 5000 shaft hp on each shaft, or 10 000 hp for the boat. This will move the boat backwards at 21 or 22 knots, and it can be stopped from full speed ahead in one and one-half minutes. These boats have gone from full speed ahead (35 knots) to 20 knots astern in less than two minutes.

FIGS. 3 AND 4—ENCLOSED AND OPEN VIEWS OF SINGLE REDUCTION GEAR

TABLE I—COMPARISON OF ENGINE EQUIPMENTS

	U.S.S. Clemson Destroyer	U.S.S. Tennessee Battleship
Rated shaft hp	28 000	28 000
Maximum shaft hp	31 000	35 000
Ship speed knots	35	21
Displacement tons	1200	33 000
Weight of main propelling engines—tons	76	615
Sq. ft. deck space occupied by main propelling engines and aux. (exclusive of boiler rooms)	1550	12 000*
Lbs. steam per shaft hp-hr. at rated load and same operating conditions—250 lbs. steam, dry and saturated; 28 inches vacuum	10.5	11.5
Propeller speed, r.p.m.	450	170

*Engine room and aux. on two decks.

The depth of water in which a boat is moving has a very marked effect on the speed. In general, the deeper the water, up to at least one boat length, the faster the boat will go with a given propulsive power, but with long narrow boats of the torpedo or destroyer type, there may be a shallow depth at which the boat speed will actually be higher than at any greater or lesser depth. This is shown quite clearly by Fig. 6, made from trial data. This has also been indicated in trials of the destroyers of the Clemson type.

No exact trial data is available on the Henley or Mayrant, as they were rushed into active service immediately on completion of the machinery installation. The Mayrant made a very good record with the cruising turbines; several long runs which permitted their use showing a very good economy, with the long resultant cruising radius without refueling.

In unofficial builders trials on the Clemson at about 30 knots, the machinery developed a shaft horse-

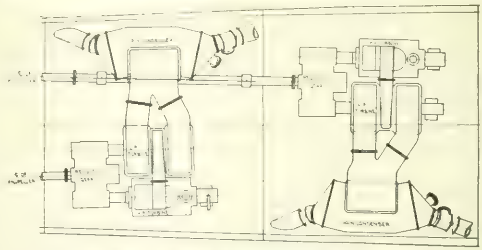


FIG 5—OUTLINE OF MACHINERY ARRANGEMENT

TABLE II—PERFORMANCE AT VARIOUS SPEEDS

Ship speed in knots	35	25	20	15	12
Shaft horse-power	28 000	10 000	4200	1500	750
Percent of full-speed power	100	36	15	5.5	2.7
Guaran. steam consumption, lbs.	10.75	10.75	12.0	15.1	18.5

power on slightly less than one pound of oil per hour; at 35 knots slightly over one pound. No steam con-

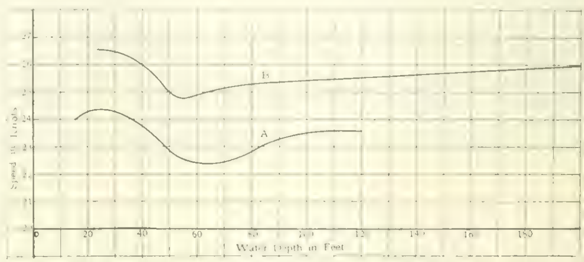


FIG. 6—SPEED CURVES OF DESTROYERS IN VARIOUS DEPTHS OF WATER AND CONSTANT INDICATED HORSE-POWER

A—2200 indicated horse-power, 132 tons, 145 feet long.
B—5000 indicated horse-power, 374 tons, 200 feet long.

sumption readings were taken. These results will undoubtedly be improved on the official trials.

Tertiary Windings in Transformers

Their Effect on Short-Circuit Currents

J. F. Peters

Tertiary windings, when placed in transformer banks, are primarily for the purpose of supplying that part of the necessary magnetizing current to produce a sine wave of voltage that cannot be drawn from the line when certain schemes of connections are employed. However, tertiary windings can be used in many cases to limit single-phase short-circuit currents to relatively small values. An effort will be made in the following to explain the functioning of these windings for the two cases of application mentioned and to show what capacity they should have.

THE PERMEABILITY of sheet steel used in the construction of transformers changes as the magnetic flux density increases, so that the rate of variation of the latter is less than that of the magnetizing current producing it. The induced voltage in the secondary, and also the counter-electromotive force in the primary of a transformer, are proportional to the rate of change of the magnetic flux enclosing these windings. The rate of change of a sine function is a sine function 90 degrees later in time phase. Therefore, to produce a voltage having a sine wave, the rate of change in the magnetic flux also must be a sine wave.

On account of the change in permeability of the iron at different flux densities, the magnetizing current producing a sine wave of magnetic flux cannot be a sine wave. It has been found by analysis that the magnetizing current of a transformer producing a sine wave of voltage has a considerable third harmonic component. It also contains the higher odd harmonics (5th, 7th, 9th, etc.), but to a much less degree.

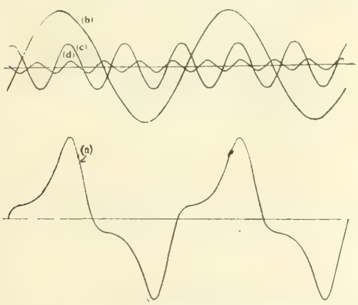


FIG. 1—TRANSFORMER MAGNETIZING CURVE

That the magnetizing current must contain a comparatively large third-harmonic component is shown by the following:— A comparatively small current is required for the first part of the magnetic flux cycle, the density being low, while as the maximum flux density is approached, a much larger current in proportion is required. Therefore, the current wave necessary to produce a sine wave of flux will be peaked. There will be only one peak per half cycle corresponding to the maximum flux density, and this peak must be made up largely of a harmonic that has but one maximum value, in the proper direction, per half cycle of the fundamental. The third harmonic has one and one-half cycles per half cycle of the fundamental and it is so located that its one maximum occurs a little later than the fundamental maximum. The other two maxima of the third supress the fundamental in the first and last part of the half cycle.

In Fig. 1, *a* represents the magnetizing current of a transformer. It is the resultant of a component at fundamental frequency *b*, a third harmonic component *c*, and a fifth harmonic component *d*. The magnitude of *c* is 40 percent of the fundamental, and *d* is 10 percent of the fundamental. The harmonics higher than the fifth were neglected for simplicity.

The magnetizing current of a transformer does not contain any even harmonics. This is obvious from the fact that the plus and minus half waves of a complete cycle of magnetizing current are the same. That is, it takes the same value of current to magnetize the core in one direction as it does in the other. Therefore, all the harmonics as well as the fundamental must, at the beginning of the second half cycle be of the same value but in the direction opposite to that at the beginning of the first half. Only odd harmonics will satisfy this condition. While the fundamental passes through one half cycle, the third harmonic passes through one and one-half cycles and the fifth harmonic through two and one-half cycles, etc. All odd harmonics end with an odd number of one-half cycles and are therefore in the same relative position, but in the direction opposite to that at the beginning of the first half cycle. If the magnetizing current does not contain all of the harmonics necessary to produce a sine wave of voltage, then the voltage will contain those harmonics which the magnetizing current lacks, and possibly more. For example, when the magnetizing current does not contain the necessary third-harmonic component, the induced voltage contains a third-harmonic component.

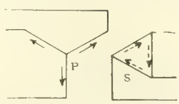


FIG. 2—STAR-DELTA CONNECTION

The most frequent arrangement of transformers is the use of three single-phase units connected into a three-phase bank, delta on the low-voltage side and star on the high-voltage side, as shown by Fig. 2. Assume that a bank so connected is used to step-down the voltage, and that the magnetizing currents for each of the three units are as indicated by *a*, Fig. 1. The magnetizing currents then for each phase contain, in addition to the fundamental, a third and a fifth harmonic compon-

ent. Since the transformers are connected in three-phase relationship, their voltages are 120 degrees apart and, therefore, their magnetizing currents are 120 degrees apart. The magnetizing currents for the three units are shown in their proper phase position in Fig. 3 (a). The three leads feeding the bank carry the current both to and from the transformers and, therefore, the resultant of the current in the leads must at all times be zero. But the resultant of the magnetizing currents for all three units in this case is not zero, but has a resultant as shown dotted in Fig. 3 (a) which is obtained by combining the three waves. Therefore, not all of the magnetizing current for this connection can be supplied through the three leads.

If the other higher harmonics of the magnetizing current had been taken into account (7th, 9th, 11th, etc.) in the above analysis, it would be found that they all sum up to zero, except the third and odd multiples of the third (9th, 15th, etc.). Therefore, the necessary third-harmonic component and its multiples to produce a sine wave of voltage must be supplied in some other

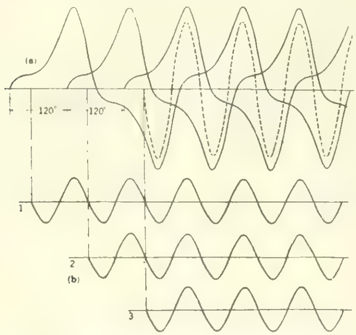


FIG. 3—MAGNETIZING CURRENTS OF THREE SINGLE-PHASE TRANSFORMERS CONNECTED STAR-DELTA

manner for this scheme of connections, since they cannot be drawn from the line.

In Fig. 3 (b) at *1*, *2*, and *3* are plotted the third-harmonic components of the magnetizing currents for the three phases in their proper phase position with respect to the composite waves in the same figure at (a). These third-harmonic currents are all in the same direction at corresponding points. In Fig. 2, the full arrows indicate the instantaneous directions in which the third-harmonic currents should flow in the primary or star side. Since the third harmonic currents of all three phases are in phase with each other, they have no return path in a star-connected circuit; therefore, they cannot flow. Consequently, third-harmonic voltages will be generated due to the absence of the third-harmonic currents. These voltages are all in the same direction, since their components of the magnetizing currents are all in the same direction.

The generated or induced third-harmonic voltages appear in both the primary and secondary windings, but the delta-connected secondary forms a closed local circuit for its third harmonic voltage. Consequently, a third-harmonic current will circulate around this circuit, as indicated by the dotted arrows in Fig. 2, and produce a third-harmonic flux which will cut both the primary and secondary windings. This flux will generate in both windings a counter third-harmonic voltage approximately equal and opposite to the one caused by the absence of the third-harmonic current in the primary. This results in cancelling all of the third-harmonic voltages, except that due to the reactance of the transformer, which is generally so small that it is of no consequence. It is evident from the foregoing that the third-harmonic component of the magnetizing current for a bank of transformers connected star-delta is supplied by a circulating current in the closed delta.

It would be found by a similar analysis that the 9th and 15th harmonic currents and all odd multiples of the third are supplied by a circulating current in the delta, while all other odd harmonic currents are drawn from the line. The magnitude of this circulating current is

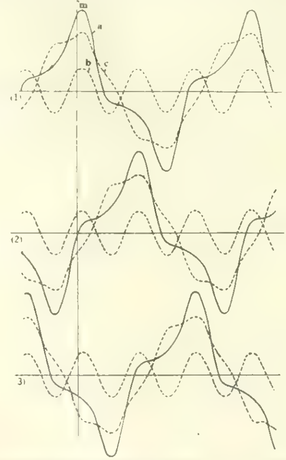


FIG. 4—MAGNETOMOTIVE-FORCE WAVES IN A THREE-PHASE CORE-TYPE TRANSFORMER

such that when it is multiplied by the turns in the delta, the product is equal to that of the required harmonic current in the primary multiplied by the primary turns. That is, the magnetomotive force is the same whether supplied by the primary or by the secondary, or by a tertiary.

The foregoing statements are based on a star-connected primary delta-connected secondary bank of three single-phase transformers, but it applies equally well to a star-connected bank containing tertiary windings, except that in the latter case, the third, ninth, fifteenth, etc., harmonic components of current would circulate in the tertiary. It will therefore be seen that the tertiary windings for a bank of three single-phase transformers connected star-star supplies that part of the magnetizing current, k.v.a. or magnetomotive force, as you please, that has the same instantaneous and vector direction in all three phases; that is, the 3rd, 9th, 15th, etc., harmonic components. These components for any definite

bank of transformers represent a definite amount of wattless magnetic energy and can be expressed in ampere-turns or in k.v.a. It will, therefore, be seen that there is no definite relation between the turns in this winding and the primary or secondary winding. If the turns in the tertiary winding be made large in number, its current will be correspondingly small, or vice versa.

It is sometimes convenient to use the tertiary winding for supplying an auxiliary load as well as the components of the magnetizing currents. In such cases, the turns for the tertiary winding are selected to give the desired voltage for the auxilary load, and the current capacity then equals the square root of the sum of the squares of the auxiliary load current and the components of magnetizing current. These currents combine as the square root of the mean squares because they are at different frequencies, the auxiliary load being at fundamental frequency and components of magnetizing current at 3rd, 9th, 15th, etc., harmonics.

The magnitudes of these components vary considerably for different transformers. For the average power transformer the third-harmonic component is approximately 25 to 30 percent of the composite magnetizing current. The 9th, 15th, etc., are generally negligible. Then, for a bank of transformers that require a total magnetizing k.v.a. of 6 percent, the ter-

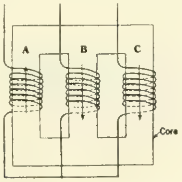


FIG. 5 FLUX PATHS IN A CORE-TYPE TRANSFORMER

tiary, when supplying the components of magnetizing current only, would have a capacity of approximately 1.8 to two percent of the rating of the bank.

THREE-PHASE TRANSFORMERS

The foregoing considerations were based on banks made up of single-phase units connected for polyphase transformation. If the three phase-banks consisted of three-phase units of the so called "shell form," the conditions with respect to magnetizing currents and higher harmonic voltages and tertiary windings would be substantially the same as for single-phase units connected in the same relation. But if the three-phase banks consist of three-phase units of the core type construction, the conditions with respect to magnetizing currents and higher harmonic voltages in the star-star-connected bank are considerably changed and tertiary windings are not required.

With the latter type of construction, the magnetic circuit for the three phases are mutually connected, in that the magnetic flux of any one phase has its return path through the other two phases. Now, since the magnetic fluxes go and return through the same three cores, it is evident that the resultant of the three fluxes in any one direction must at all times be zero. But, if there are any third-harmonic voltages in the phases due to the absence of the third-harmonic magnetizing currents in the star-star-connected unit, they are induced in the same direction in all three phases and, therefore, their third-harmonic magnetic fluxes are all in the same direction. This would require that the third-harmonic flux return outside of the cores through high reluctance paths. They would consequently be of very small value.

It would appear from the above that third-harmonic voltages which are due to the absence of the third-harmonic component of magnetizing currents in the star-star connection are prevented in the three-phase core-type units by the high reluctance return paths of the third-harmonic magnetic fluxes. But this is not strictly true; what really happens is that the deficit in magnetomotive force in parts of the cycle in each phase is supplied by the other two phases. Fig. 4 shows three magnetomotive force waves *1*, *2*, and *3*, 120 degrees apart; *a* is the required wave of magnetomotive force to produce a sine wave of magnetic flux; *b* is the third-harmonic component of the required magnetomotive force wave, and *c* is the magnetomotive force wave that is drawn from the line. It is wave *a* minus wave

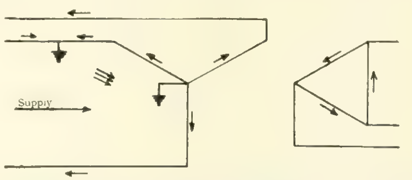


FIG 6—CURRENTS IN A STAR-DELTA CONNECTED BANK, WITHOUT TERTIARY WINDING

$$I_s = \frac{100\ I_n}{Z_o}$$

b. Referring to point *m*, it will be seen that *c* in *1* is lacking sufficient magnetomotive force, while *2* and *3* at the same point have a surplus of magnetomotive force. Consider this point on the cycle to be such as to have a magnetic flux up through core *A* in Fig. 5, and down through *B* and *C*. The extra magnetomotive force tending to produce the surplus of flux down through *B* and *C* will be expended in supplying the deficit up through *A*, *A* being the return path for *B* and *C*. In this way there is an interchange of magnetomotive forces between phases, which results in the production of a sine wave of magnetic flux and, therefore, a sine wave of voltage in all three phases.

SHORT CIRCUIT CURRENTS

Since the tertiary windings are placed only in three-phase banks of transformers connected star-star, the following discussion will be confined to that connection. The short-circuit currents are expressed in terms of normal full-load current I_n and the impedance is expressed in percent. Z_0 is the percent impedance between primary and secondary windings at rated load and Z_t is the percent impedance between tertiary

winding and primary or secondary corresponding to a load in the tertiary equal to the rating of the transformer. I_s is the short-circuit current in the transformer in terms of normal rated load and is represented at various parts of the circuit by one small arrow. Two small arrows represent $2I_s$, etc. The current that circulates in the tertiary under short-circuit is at fundamental frequency.

In Figs. 6 and 7 it is assumed that the neutral at the supply is not grounded. If the neutral of the supply is grounded, for these figures, the short-circuit currents are simply single-phase. Grounding the neutral of the supply for Fig. 8 would not alter the conditions shown. In these figures it is assumed that the supply voltage during the short-circuit is maintained at normal value. The short-circuit current is limited principally for Fig. 8 and entirely for Fig. 7 by the impedance between the tertiary and main windings. This impedance is generally made large in order to minimize the short-circuit current and also to keep the load and consequently the size of the tertiary winding small.

FIG. 7—CURRENTS IN A STAR-STAR CONNECTED BANK, CONTAINING A TERTIARY WINDING

When a ground occurs on the primary side, $I_s = \frac{100\ I_n}{Z_t}$

Figs. 7 and 8 apply to single-phase transformers of either core or shell types and to three-phase, shell-type units, but not to three-phase, core-type units. The latter do not require tertiary windings. When one line of a grounded neutral, three-phase, core-type bank becomes grounded, the short-circuit current is as indicated by Figs. 7 and 8, where Z_0 is the impedance between primary and secondary on one phase of the unit and Z_t is the impedance between the windings on one phase and the windings on the other two phases. That is, the short-circuited phase becomes the secondary for the other phases as primaries.

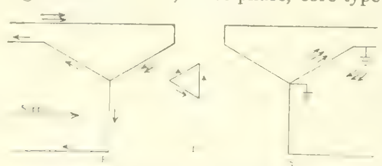


FIG. 8—CURRENTS IN A STAR-STAR CONNECTED BANK, CONTAINING A TERTIARY WINDING

When a ground occurs on the secondary side, $I_s = \frac{100\ I_n}{2Z_o + Z_t}$

The size of the tertiary winding for grounded neutral operation is fixed by the short-circuit k.v.a. rather than the third-harmonic component of magnetizing current. This winding must carry the short-circuit k.v.a. long enough for the circuit opening devices to operate. The length of time required for automatic circuit breakers to remove the faulty circuit is generally not more than three seconds. During this interval of time there is very little heat radiated from the tertiary winding, therefore, it must contain sufficient copper to store its short-circuit I^2R loss by thermal capacity during this relatively short interval of time.

The conditions under which tertiary windings are used and their effect on short-circuit currents when one line becomes grounded are summarized in Table I. This tabulation is based on the assumption that normal voltage is maintained at the primary terminals of the bank. It applies to all types of transformers. Of course where three-phase, core-type units are used, tertiary windings are assumed absent and the current as given for these windings then has no significance, but the maximum currents given for the windings are correct. The impedance Z_t for this case, as stated before, is the impedance between the windings on different phases.

TABLE I—EFFECT OF TERTIARY WINDING ON SHORT-CIRCUIT CURRENTS, WHEN ONE LINE BECOMES GROUNDED

Connection of Transformer Bank		Supply	Side on Which Fault Occurs	Tertiary	Short-Circuit Current	
Primary	Secondary				In Tertiary	In Main Winding
Delta	Delta	Grounded or Isolated	Primary or Secondary	No	0	0
Delta	Star	Grounded or Isolated	Primary or Secondary	No	0	0
Star	Star	Grounded or Isolated	Primary or Secondary	Yes	0	0
Star	Delta	Grounded or Isolated	Primary or Secondary	No	0	0
Delta	Star Grounded	Grounded or Isolated	Primary	No	0	0
Delta	Star Grounded	Grounded or Isolated	Secondary	No	0	$\frac{100\ I_n}{Z_o}$
Star Grounded	Delta	Grounded	Primary	No	0	0
Star Grounded	Delta	Grounded or Isolated	Secondary	No	0	0
Star Grounded	Delta	Isolated	Primary	No	0	$\frac{100\ I_n}{Z_o}$
Star Grounded	Star	Grounded	Primary or Secondary	No	0	0
Star Grounded	Star	Isolated	Primary	Yes	$\frac{100\ I_n}{Z_t}$	$\frac{100\ I_n}{Z_t}$
Star Grounded	Star	Isolated	Secondary	Yes	0	0
Star Grounded	Star Grounded	Grounded	Primary	No	0	0
Star Grounded	Star Grounded	Grounded	Secondary	No	0	$\frac{100\ I_n}{Z_t}$
Star Grounded	Star Grounded	Isolated	Primary	Yes	$\frac{100\ I_n}{Z_t}$	$\frac{100\ I_n}{Z_t}$
Star Grounded	Star Grounded	Isolated	Secondary	Yes	$\frac{100\ I_n}{2Z_o + Z_t}$	$\frac{300\ I_n}{2Z_o + Z_t}$
Star	Star Grounded	Grounded or Isolated	Primary	Yes	0	0
Star	Star Grounded	Grounded or Isolated	Secondary	Yes	$\frac{100\ I_n}{2Z_o + Z_t}$	$\frac{300\ I_n}{2Z_o + Z_t}$

Interchangeability of Squirrel-Cage Rotors

B. B. Ramey

IN MILLS and factories where large numbers of induction motors are in service, emergencies often arise due to break downs, and repair parts are needed at once. While burnouts are not frequent on motors with squirrel-cage windings they occur at times; also rotors and shafts are at times damaged in service, and when any of these troubles occur it is usually necessary to replace the complete rotating part. This is undoubtedly the quickest way of making the repair. It often happens that a spare rotor for the particular motor in trouble is not available. The following comments may serve to give some new ideas for such an emergency and help to get the motor back in service by using rotors for motors of other ratings that may be at hand. Thus the delay due to awaiting a new rotor from the manufacturer may be avoided.

The squirrel-cage rotor with its winding of bars and resistance rings fastened together by any of the well known methods, has no groupings for poles, and when placed in a properly wound stator will respond to the synchronous speed that the particular stator may be wound for. The horse-power output is therefore determined by the stator that is used, since horse-power is proportional to the product of speed and torque. The squirrel-cage rotor does not set the speed nor the horse-power, but does control them to a certain extent, for the percent slip is largely determined in the rotor and the starting torque and heating are affected somewhat, as outlined later.

It is to be understood, of course, that the rotor is correct mechanically to fit the stator. That is, the length of iron and air-gap should be correct. The air-gap could be off a few thousandths of an inch or the iron width could be slightly less or greater than the iron width of the stator without causing any trouble.

The other feature to consider is the electrical characteristics of the rotors. As stated above the rotor will run at a synchronous speed as determined by the stator. In a line of motors of a given manufacturer, the rotor windings are usually such as to have a greater total actual resistance, the greater the number of poles. That is a rotor for an eight pole motor has a greater total resistance than a rotor for a six pole motor and for a ten pole motor greater than for an eight pole motor, etc. The proportion of actual resistance in the resistance rings to that in the bars changes generally and is greater on the rotors for motors of larger numbers of poles. The effective resistance on a given rotor is, however, determined by the number of poles of the stator in which this rotor is being used and is usually greater for a small number of poles than for a large number of poles. Also the actual resistance and effective resistance in the bars are, in general, the same for rotors built for ratings of different numbers of poles, assuming the total bar section and length of bars to be the same. The difference is in the resistance rings. For instance a six pole motor will usually have copper rings of large section and a ten pole motor will very likely have rings of copper of small section or rings of high resistance material such as brass of proportionate section. The path of the current in the six pole ring, however, is ten-sixths of that in the ten pole rotor and for the same rings the effective resistance is greater as the square of this ratio. The greater effective resistance means more starting torque and higher percentage slip, that is the full load speed is slightly lower and consequently there is a greater loss in the rotor; and vice versa for the lower effective resistance. By effective resistance is meant the resistance that is effective by virtue of the length of the path taken by the current in going through the bars or the resistance rings.

Assuming that the rotors are correct mechanically, the interchanging of the rotors will have in general about the following effect. If a ten pole motor is having rotor trouble and a rotor from a six pole motor is used in it, the percent slip will be less, the starting torque lower, the efficiency slightly higher and consequently there will be less heating. If a six pole motor is having rotor trouble and a rotor from a ten pole motor is used in it, the percent slip will be greater, the starting torque higher, the efficiency slightly lower and consequently there will be increased heating. Efficiency is not of prime importance, however, in case of emergencies, such as are being considered, but starting torque and heating are important. Similar interchanges of rotors could be carried out such as four and eight poles, eight and ten poles, eight and twelve poles, ten and twelve poles, etc. remembering that the greater the difference in the number of poles, the greater the effect on the items of performance noted above. It is well, therefore, not to substitute rotors, when the difference in number of poles is too great, such as two and ten, or four and ten.

In making the interchange of rotors, if a rotor of a different number of slots than the standard rotor for the motor is used it is best to use a rotor with a number of slots that is at least fifteen percent greater or less than the number of slots in the stator. Otherwise trouble due to low torque points may be experienced. The number of rotor slots will also have some effect on noise, but the question of noise is not important in most mills and factories and a noisy motor could be tolerated in an emergency.

Aside from the question of quick repair in cases of break downs there are also other cases in which the above comments may help to save time. That is in cases where motors with high percent slip are required, such as in punch, shear and other flywheel applications.

For example a six pole motor may be available for a punch press but has a rotor that gives a low percent slip. A spare rotor for a ten pole motor that is correct mechanically may be available or there may even be a ten pole motor in service, the rotor of which could be interchanged with the six pole motor. The ten pole rotor would perhaps give the desired percent slip when used in the six pole stator and the six pole rotor would perhaps give sufficient torque when used in the ten pole stator in the service that it is on. All of this would necessarily have to be determined by trial. Since higher percent slip is desired in such a case as this, only rotors from motors with larger numbers of poles can be used, as going the other way gives a lower percent slip.

As the name plates of motors of various manufacturers are stamped differently, some having full load speed, some the synchronous speed and the majority no indication of the number of poles, the usual standard speeds are given in Table I to tie together the speeds and numbers of poles for assistance in studying or applying the information outlined in this article.

TABLE I—INDUCTION MOTOR SPEEDS

No. of Poles	Synchronous R. P. M.				Approximate Full Load R. P. M.			
	25 cy.	40 cy.	50 cy.	60 cy.	25 cy.	40 cy.	50 cy.	60 cy.
2	1500	2400	3000	3600	1450	2300	2900	3450
4	750	1200	1500	1800	720	1150	1450	1750
6	500	800	1000	1200	480	770	960	1150
8	375	600	750	900	360	575	720	870
10	300	480	600	720	285	460	575	690
12		400	500	600		380	480	575
14			428	514			410	490
16				450				430

Bakelite-Micarta Airplane Propellers

N. S. Clay

BAKELITE-MICARTA possesses a number of characteristics which make it a suitable material for airplane propeller use. Chief among these is its great strength, permanence of shape under extreme atmospheric conditions and finally a hard wear-resisting surface. It was these qualities, together with the impending scarcity of good propeller wood, which furnished the motive for the extensive development that was destined to add one more to the already numerous successful applications of bakelite-micarta.

It might be well to enumerate here some of these characteristics and their use in airplane propeller design.

1—Modulus of Rupture, 17 000 to 25 000 lbs. per sq. in. compared with 8000 to 20 000 for wood. This makes possible the use of thinner blade sections, thus increasing the efficiency. The material is well adapted for irregular or curved blades, and blade forms may be used which would be impossible with wood because of the danger of splitting.

2—High Shearing and Crushing Strength—Advantage is taken of these properties in designing a light metal hub. The heavy flanges and bolts customarily used with hubs for wooden propellers are replaced by four light keys driving directly on the micarta. It is even possible to eliminate the metal hub entirely if the engine shaft can be modified to permit the use of more keys.

3—Hard Surface—Tests indicate that propellers of this material will outwear several wooden propellers. Figs. 1 and 2 illustrate the relative wearing qualities of micarta and wood. Both propellers were run in a water spray at 1800 r.p.m., the wooden one for a few minutes only and the micarta for one-half hour. Practically the only damage done to the micarta propeller was the removal of a little paint from the leading edge, while with the wooden propeller the material was worn away considerably where unprotected by metal tips.

4—Uniformity of Material—The physical properties of several specimens of the same kind of wood may differ greatly, depending partly upon the percentage of moisture present and partly upon the natural construction of the wood. For this reason, in order to make wooden propellers which will give fairly consist-

FIGS. 1 AND 2—MICARTA AND WOODEN PROPELLER BLADES AFTER A SEVERE WATER SPRAY TEST

ent performance and strength tests, and also to prevent warping, it is necessary to use laminated construction. This method does not secure uniform strength throughout each propeller and, while some propellers of a certain design may give excellent service, others will crack, run out of track, or flutter.

Micarta propellers are molded with sheets of material arranged in layers, but not only is the material composing each sheet more uniform than is possible

with wood, but a much greater number of layers are used. This insures uniform construction.

5—Permanence of Shape—This characteristic of bakelite-micarta, the slight change and deterioration when exposed to severe atmospheric changes, is thought to be its most valuable property. The one big objection to wooden propellers is, of course, warping. Not long ago it was practically impossible to use a wooden propeller in any other climate than where it was made. Recently improved methods in handling and finishing have made the wooden propeller more serviceable, but they still have a very short life, especially in hot dry regions.

A micarta propeller was exposed to the sun, rain and wind during the whole of two summer months. It was not given a protective coating of any kind. Angle measurements taken before and after exposure disclosed an average change of less than 0.2 degrees and a change in track of only 0.02 inches. As far as inspection could determine, the propeller was in as good condition as when it was put out. Two propellers were placed in an ordinary shipping trunk and sent to the British War Department, in England, together with a copy of our blade angle measurements. They reported that the angles had not changed.

At first sight the problem of making a propeller from bakelite micarta looked difficult. The extreme hardness and toughness of the product made machining of such a large and irregular shape impractical. It was clearly a question of the possibility of molding directly to shape. This involved the molding of a larger mass than had ever been attempted before and it was questionable whether uniform quality could be maintained throughout, even if the mechanical difficulties of molding could be overcome. During the progress of the work it was found that the difficulties were not nearly as great as anticipated, except perhaps that the quality of the material and workmanship had to be held within narrowed limits.

The two types of micarta propellers manufactured so far were designed by the Airplane Engineering Department, McCook Field, Dayton, Ohio. It is to the earnest efforts of the engineers of this field that the evolution of a successful micarta propeller design is largely due.

FIG. 3—90 HORSE-POWER MICARTA PROPELLER
Shown mounted on balancing ways.

MICARTA PROPELLER FOR CURTIS TRAINING PLANE

The first propeller design submitted by the Government engineers was for the Curtis JN-4 primary training type airplane. The shape of the propeller was made as simple as possible, sacrificing aerodynamic qualities somewhat to facilitate molding.

Rating

Horse-power	90
Revolutions per minute	1450
Pitch	5 ft.
Diameter	8 ft.
Weight micarta only	36 lbs.
Weight with OX-5 metal hub	45 lbs.
Weight with special keyed hub	40. lbs.

The manufacturing equipment for this propeller was necessarily crude and inadequate. However, a number of propellers were produced which consistently passed the government strength tests and inspections. The strength was greater than necessary, 800 horsepower being successfully withstood in a number of speed tests. The flight tests were very disappointing, as the propeller allowed the engine to reach 100 to 125 revolutions per minute higher than its rated speed without securing any better plane performance. This engine speed was entirely too high for safety in training field use and the manufacturing of the propeller was finally discontinued. A photograph of one of these propellers is shown in Fig. 3.

MICARTA PROPELLER FOR DH-4 COMBAT PLANE

Rating

Horse-power	420 (Liberty)
Revolutions per minute	1750
Pitch	6.64 ft.
Diameter	10 ft.
Plane speed	132 miles per hr.
Weight micarta only	67
Weight with special keyed hub	82

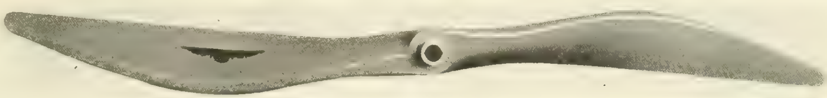


FIG 4—420 HORSE-POWER MICARTA PROPELLER

In designing this propeller it was possible to take advantage of the good qualities of the first design, and also guard against its imperfections. As a consequence a propeller was produced which possesses adequate strength and gives very good flight performance. The first propeller molded was tested at McCook Field in April 1919. The test was probably the most severe

ever given a propeller of this size and was as follows:— Thirteen hours at 600 horse-power propeller input, a speed test of 2100 r.p.m. with 1326 horse-power propeller input, finally 25.25 hours at 800 horse-power input, when failure occurred at the hub, due probably to fatigue in material overstressed in the speed test. Fig. 4 shows this propeller before test.

Fig. 5 shows the results of comparative flight tests of a micarta Liberty propeller and a wooden propeller of conventional design. A regular DH-4 airplane was used. It will be seen that while the plane speed and climbing rate is but little better with the micarta propeller than with the wooden one, the engine speed is almost 100 r.p.m. lower, signifying a higher efficiency.

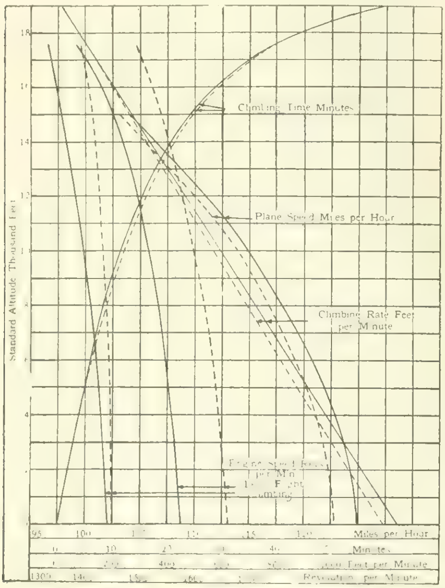


FIG. 5—COMPARISON OF FLIGHT TESTS

The lower engine speed will add appreciably to its life and the flying radius of the plane.

METHOD OF MANUFACTURING

Micarta propellers have been successfully constructed from both paper and cloth. The material is impregnated with bakelite and a definite amount placed in the mold. Molding is conducted at a high temperature for a number of hours under several hundred tons pressure, steam being used for heating and cold water for cooling. The mold for the Liberty propeller is shown in Fig. 6. The mold is shown open with the bottom pressing plate raised in such a position that the propeller can be readily removed.

After molding, the propeller is bored and fitted with the metal hub. In boring, the hole is left several thousandths of an inch under size and the hub pressed in. This insures a tight fit, eliminates chafing, and also relieves the driving pressure on the keyways to a certain extent. With the hub installed, the propeller is placed on a curing mold similar to the one shown in Fig. 7. It is clamped, thrust face down on a surface having angles corresponding to those of the propeller blades. The combination is then placed in an oven and

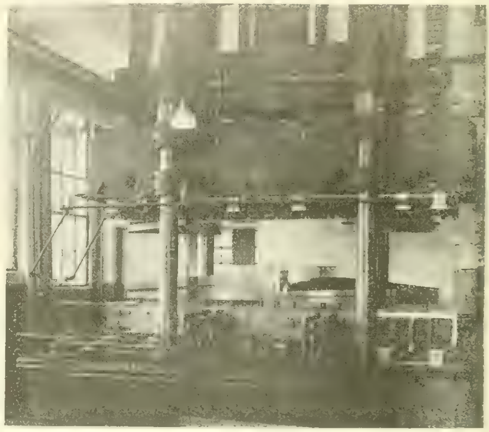


FIG. 6—MICARTA PROPELLER MOULDING PRESS

baked at a low temperature for a number of hours, when it is removed and allowed to cool before the propeller is unclamped. It has been found advisable to cure at this stage of the manufacturing process, because of the fact that any reasonable error in track or blade angles due to incorrect alignment while boring can be rectified in the curing operation. After curing, the propeller is given a coat of battleship gray paint and several coats of varnish. This forms a very durable finish.

One more characteristic especially fits bakelite-micarta for propeller use. In molding micarta, it is very easy to insert metal wires or strips wherever needed to give additional strength or rigidity. A number of small steel wires are imbedded in the material forming the leading edge of the propeller, shown in Fig. 4. This tends to make the pitch of the propeller self-adjusting, preventing the blade angles from increasing under the heavy thrust encountered while climbing.

The chief drawback to the extensive application of micarta propellers at this time is the small demand for

[illegible] RING MOULD

propellers of one design. Considerable time and money is required to construct a propeller mold and this is not practical unless quantity production is desired. With the increased use of aircraft in the future the merits of bakelite-micarta propellers will be more apparent.

Electrical Characteristics of Transmission Circuits-IV

Corona Effect

Wm. Nesbit

In 1898 Dr. Chas. F. Scott presented a paper before the A.I.E.E. describing experimental tests (made during several years previous) relating to the energy loss between conductors due to corona effect. These investigations began at the Laboratory at Pittsburgh and were continued at Telluride, Colorado, in conjunction with the engineers of the Telluride Power Company. Preliminary observations were made by Mr. V. G. Converse and were continued in notable measurements by Mr. R. D. Mershon. These investigations were later followed by the work of Professor Ryan, by Mr. R. D. Mershon, Mr. F. W. Peek, Jr., Dr. J. B. Whitehead, Mr. G. Faccioli and others. The electrical profession is particularly indebted to Mr. Peek and Dr. Whitehead for the large amount of both practical and theoretical data which they have presented to the electrical profession on the subject. Mr. Peek developed and presented the empirical formulas which follow, for determining the disruptive critical voltage, the visual critical voltage and the power loss due to corona effect. The close accuracy of Mr. Peek's formulas has been confirmed by various investigators in different sections of the country. The following deductions concerning corona have to a large extent been previously presented by Mr. Peek.

Corona, manifesting its presence usually by an electrostatic glow or luminous discharges, and audibly by a hissing sound, was clearly observed and studied in connection with electrostatic machines. It did not become a serious factor to be considered in connection with the design of commercial electrical apparatus until the increasing generator and transmission voltage emphasized its importance.

Although it is usual to think of corona effect only in connection with high-voltage transmission lines, it has received not a little thought of late by the designers of high-voltage generators and motors, notably large, high-voltage turbogenerators. By effectively insulating the portion of the conductor embedded in the iron of the armatures of alternating-current machines, particularly with mica, punctures to ground due to corona effect are not likely to occur. However, at the ends of the armature coils (where it is difficult to employ mica for insulating), where air is partially depended upon as an insulating medium between coils and ground, corona may appear. The presence of these corona stresses results in disintegrating and weakening some kinds of insulating materials, causing them to break down after a period of service. This deterioration of insulation may be due to local heating, mechanical vibration or chemical formations in the overstressed air, such as ozone, nitric acid, etc.

Higher voltages are being chosen as an economic means for reducing loss in transmission. These higher voltages may result in corona loss far in excess of the saving in transmission loss due to the adaptation of the higher voltages. It is, therefore, pertinent that particular consideration be given to the limitation of corona loss when the choice of conductors is made. This consideration will sometimes make it desirable to take advantage of the higher critical voltage limits of aluminum conductors (with steel reinforced centers) of an equivalent resistance, due to their greater diameter; or it may be desirable to obtain the necessary larger diameter by the use of copper conductors having some form of nonconducting centers or, for still larger diameters, of aluminum conductors having such centers, in order to avoid skin effect. The use of copper conductors having hemp centers has in some instances given mechanical trouble.

The critical voltage at which corona becomes manifest, is not constant for a given line, but is somewhat dependent upon atmospheric conditions. Assuming a line employing conductors just within the critical voltage limitations for the conditions to be met, the corona loss in such a line would be almost negligible during fair weather, but during stormy weather, (particularly during snowstorms) this corona loss would be many times what it is during fair weather. On the other hand, since the storm will usually not appear over the whole length of lines at the same time and since storms occur only at intervals, it may often be economical to allow this loss to reach fairly high values during storms. Fog, sleet, rain and snowstorms lower the critical voltage and increase the losses. The effect of snow is greater than any other weather condition. Increase in temperature or decrease in barometric pressure lowers the voltage at which visual corona starts.

The critical voltage increases with both the diameter of conductors and their distance apart. This sometimes makes it desirable to use aluminum conductors as previously stated. It also increases with the horizontal or vertical arrangement of conductors, due to the fact that the two outside conductors considered as a pair are twice as far apart as are the other pairs. The same general rules apply to stranded conductors as to solid conductors, the actual diameter of the former being considered as the effective diameter of the conductor.

The losses due to corona effect increase very rapidly with increase in voltage after the critical voltage has been reached. A long transmission line having considerable capacitance may deliver a higher voltage than appears at the generator end of the line due to capacitance effect. The corona loss would in this case be greater per mile at the receiving end than at the sending end of the line.

The magnitude of the losses, as well as the critical voltage, is affected by atmospheric conditions;—hence they probably vary with the particular locality and the season of the year. Therefore, for a given locality, a voltage which is normally below the critical point, may at times be above the critical voltage, depending upon changes in the weather.

The material of the conductors does not seem to affect the losses. Sometimes the conductors of new transmission lines, when first placed in service will show visual corona, which may entirely disappear after a few hours or weeks of service. This may be due to scratches, particles of foreign substances, etc., on the conductors which are eliminated after the voltage stress has been kept on the conductors for a short time. Under such conditions the corona loss will also become less as the visual effect disappears.

The loss of power due to corona effect increases with frequency and increases as the square of the excess voltage above a certain critical voltage referred to as the "disruptive critical voltage" e_0. This disruptive critical voltage is that voltage, at which a certain definite and constant potential gradient is reached at the conductor surface. This gradient g_0 is 30 kv maximum (21.1 kv effective) per centimeter, or 76.2 kv maximum (53.6 kv effective) per inch. These values are based upon an air density at sea level (25° C., 29.92 inches or 76 cm. barometer). This gradient is independent of the size of conductors and their distance apart, but is proportional to the air density, that is to the barometric pressure and the absolute temperatures. It may be considered as the dielectric strength of air. The presence of corona at a certain point of the system shows that a critical electric stress has been exceeded at that point. The corona loss is also proportional to the square root of the conductor radius r and inversely proportional to the square root of the conductor spacing.

The law by which corona losses increase with the voltage does not give a very steep curve, but a rather mild curve following the quadratic law at and above the critical limit. In other words there is no sharp elbow in the curve above which the losses increase very rapidly with the voltage and which could be adopted as the normal operating point of the circuit.

Table XXII, indicating the voltage limitations due to corona effect, has been worked up from Mr. F. W. Peek's formula as indicated at the bottom of the table. The values in this table are conservative and may in many cases be exceeded. They are the effective e_0 disruptive critical voltage between conductors for fair weather based upon δ values for 25 degrees C. (77 degrees F) and m_0 values of 0.87 for cable and 0.93 for wire. With these table values, corona loss should not be excessive during storms. If the values of Table XXII indicate that the conductors contemplated are close to the limit due to corona effect, a careful check should be made by the formula to determine definitely the corona loss for such conductors under storm operating conditions.

F. W. PEEK'S CORONA FORMULAE

Disruptive Critical Volts, Fair Weather (parallel wires)

$$e_0 = 2.302\, m_0 g_0 \delta r \log_{10} \frac{s}{r} \quad \ldots\ldots\ldots\ldots (20)$$

effective kv to neutral,—

Visual Critical Volts—Fair Weather (parallel wires)

$$e_v = 2.302\, m_v g_0 \delta r \left(1 + \frac{0.189}{\sqrt{r\delta}}\right) \log_{10} \frac{s}{r} \quad \ldots (21)$$

effective kv to neutral

Power Loss (fair weather)—

$$P = \frac{390}{\delta}(f + 25)\sqrt{\frac{r}{s}}\,(e - e_0)^2\, 10^{-5} \quad \ldots\ldots\ldots (22)$$

kw per mile of each conductor

Power Loss (Storm)—Storm power loss is higher and can generally be found with fair approximation by assuming e_0 = 0.80 times fair weather e_0. It generally works out in practice that the e_0 voltage is the highest that should be used on transmission lines ....(*22A*)

All of the above voltages are to neutral. To find voltages between lines multiply by 1.73 for three-phase, and by 2 for single phase.

Notation—

e = Effective applied voltage in kv to neutral. (This will vary at different points of the circuit and at different loads. At low loads and long lines of high voltage it may be higher at the receiving end than at the generator end due to inductive capacitance)

e_0 = effective disruptive critical voltage in kv to neutral. It is the voltage that gives a constant break down gradient for air of 76 kv maximum per inch, the "elastic limit" at which the air breaks down. Visual corona does not start at the disruptive critical voltage, but at a higher voltage e_v.

e_v = effective visual critical kv to neutral (voltage at which visual corona starts)

P = power loss in fair weather in kw per mile of *single* conductor.

δ = $\frac{17.9b}{459 + t}$. This takes care of the effect of altitude and temperature, (air density). It is 1 at 25 degrees C. (77 degrees F.) and 29.92 inches (76 cm.), barometric pressure.

g_0 = 53.6 kv per inch effective (disruptive gradient of air)

b = barometric pressure in inches.

t = maximum temperature in degrees F.

f = frequency in cycles per second.

m_0 = irregularity factor.
= 1 for polished wires.
= 0.98 to 0.93 for roughened or weathered wire.
= 0.87 to 0.83 for cables.

m_v = m_0 for wires (1 to 0.93)
= 0.72 for local corona all along cables (7 strands)
= 0.82 for decided corona all along cables (7 strands)

r = radius of conductor in inches.

s = spacing in inches between conductor centers, based upon the assumption of a symmetrical triangular arrangement. For three-phase irregular flat or triangular spacing take $s = \sqrt[3]{ABC}$. For three-phase regular flat spacing take $s = 1.26A$.

Theoretically, if the conductors were perfectly smooth, no loss would occur until the critical voltage, e_v is reached, when the loss should suddenly take a definite value, equal to that calculated by quadratic law, with e_v as the applied voltage and e_0 as the critical voltage in the equation. It should then follow the quadratic law for all higher voltages. On the weathered conductors used in practice, the quadratic law is followed over the whole range of voltage, starting at e_0.

Example:—In order to show the variation in corona loss at different voltages and for different weather conditions, Table D has been calculated for No. 0 stranded copper conductors (105 560 circ. mils, 0.373 in. diameter) and for steel reinforced aluminum conductors (167 800 circ. mils, 0.501 in. diameter) having an quivalent resistance but greater diameter. F. W. Peek's formulas were used and the following assumptions were made:—

f = 60 cycles.
m_0 = 0.87
m_v = 0.72
g_0 = 53.6

r = 0.186 in. for copper = 0.250 in. for aluminum.
s = 144 inches (delta arrangement of conductors).
b = 28.9 corresponding to an altitude of 1000 feet.
t = 77 degrees F. and therefore $\delta = 0.967$.

$\frac{s}{r}$ = 774 for copper = 576 for aluminum

$\log_{10} 774 = 2.89$ and $\log_{10} 576 = 2.76$

$\sqrt{\frac{r}{s}}$ = 0.036 for copper and 0.0415 for aluminum.

DISRUPTIVE CRITICAL VOLTAGE—Fair Weather

$$e_0 = 2.302\ m_0\ g_0\ \delta\ r \log_{10} \frac{s}{r} \quad (20)$$

effective kv to neutral

For the Copper Conductors

$$e_0 = 2.302 \times 0.87 \times 53.6 \times 0.967 \times 0.186 \times 2.89$$

= 55.8 kv to neutral (96 500 volts between conductors).

Table XXII gives, by interpolation, the limitation of e_0 for above conditions, as 96 500 volts between conductors. To find e_0 to neutral for any other altitude or temperatures insert the corresponding values of δ for the altitude and temperature in the formula.

TABLE D—WORKING TABLE—δ (DENSITY) VALUES

Altitude and Temperature Correction Factors

$\delta = \frac{17.9b}{459 + t}$ where b = barometric pressure in inches and t = temperature in degrees F.

Altitude in Feet	Barometer		δ Values for Different Temp.		
	In Inches	In Cm.	0° C. (32° F.)	25° C. (77° F.) *	50° C. (122° F.)
Sea Level	30.0	76.2	1.09	1.00	0.925
500	29.45	74.8	1.07	0.985	0.910
1000	28.90	73.3	1.05	0.967	0.892
1500	28.30	71.8	1.03	0.947	0.873
2000	27.80	70.7	1.01	0.932	0.860
2500	27.25	69.2	0.955	0.912	0.841
3000	26.80	68.0	0.980	0.897	0.827
4000	25.75	65.3	0.940	0.860	0.793
5000	24.70	62.7	0.902	0.827	0.762
6000	23.90	60.7	0.875	0.800	0.738
7000	22.95	58.3	0.840	0.770	0.710
8000	22.05	56.0	0.805	0.738	0.682
9000	21 30	54.1	0.778	0.712	0.657
10 000	20.50	52.1	0.750	0.687	0.633
12 000	19.00	48.3	0.697	0.637	0.588
14 000	17.55	44.7	0.643	0.588	0.543
15 000	16.90	42.9	0.618	0.566	0.522

*This column contains the values for δ which were used in determining the values of e_0 in Table XXII. That is, the values for sea level in Table XXII multiplied by these δ values gives the e_0 values of the table for the higher altitudes.

For the Aluminum Conductors

$$e_0 = 2.302 \times 0.87 \times 53.6 \times 0.967 \times 0.25 \times 2.76$$

= 71.5 kv to neutral (123 500 volts between conductors).

Table XXII gives (by interpolation) the limitation for above conditions as 123 500 volts between conductors.

To find e_0 to neutral for any other altitude or temperature insert the corresponding value of δ for that altitude and temperature in the formula.

DISRUPTIVE CRITICAL VOLTAGE—Stormy Weather

e_0 during storm = approximately 80 percent e_0 during fair weather.

For the Copper Conductors

e_0 for storm = 55.8 × 0.80 = 44.6 kv to neutral or 77 000 volts between conductors.

For the Aluminum Conductors

e_0 for storm = 715 × 0.80 = 57.2 kv to neutral or 98 800 volts between conductors.

VISUAL CRITICAL VOLTAGE—Fair Weather

$$e_v = 2.302\ m_v\ g_0\ \delta\ r \left(1 + \frac{0.189}{\sqrt{r\,\delta}} \right) \log_{10} \frac{s}{r} \ldots (21)$$

effective kv to neutral

For Copper Conductors

$$e_v = 2.302 \times 0.72 \times 53.6 \times 0.967 \times 0.186 \left(1 + \frac{0.189}{0.424} \right) 2.89$$

= 66.4 kv to neutral (115 000 volts between conductors).

To find e_v to neutral for any other altitude and temperature, insert the corresponding values of δ for that altitude and temperature in the formula above.

For the Aluminum Conductors

$$e_v = 2.302 \times 0.72 \times 53.6 \times 0.967 \times 0.25 \left(1 + \frac{0.189}{0.492} \right) 2.76$$

= 82 kv to neutral (141 500 volts between conductors).

To find e_v to neutral for any other altitude and temperature, insert the corresponding values of δ for that altitude and temperature in the formula above.

POWER LOSS

$$P = \frac{390}{\delta} (f + 25) \sqrt{\frac{r}{s}} (e - e_0)^2\ 10^{-5} \ldots\ldots\ldots (22)$$

kw per mile of each conductor

The corona power loss corresponding to various conditions for the above circuit has been calculated by formulae (22) and (22A). They are given in Table E. However, in order to illustrate the application of the power loss formula the losses for the following conditions are determined below. Assuming that the No. 0 stranded copper conductors will be operated at 105 kv between conductors (60.7 kv to neutral).

For Fair Weather—Max. Temp. 50 degrees C. (122 degrees F.)—E_0 = 51.3 *kv.*

$$P = \frac{390}{\delta} (f + 25) \sqrt{\frac{r}{s}} (e - e_0)^2\ 10^{-5} \ldots\ldots\ldots (22)$$

kw per mile of each conductor

$$P = \frac{390}{0.892} (60 + 25) \times 0.036\ (60.7 - 51.3)^2\ 10^{-5}$$

= 1.2 kw per mile of each conductor or 3.6 kw per mile for three conductors.

For Stormy Weather—Max. Temp. 25 degrees C. (77 degrees F.)—E_0 = 55.8 × 0.8 = 44.6 *kv.*

$$P = \frac{390}{0.967} (60 + 25) \times 0.036\ (60.7 - 44.6)^2\ 10^{-5} \quad (22A)$$

= 3.2 kw per mile of each conductor or 9.6 kw per mile for three conductors.

By applying formula (20) to the above case it develops that the fair weather values of e_0 are for 25 degrees C. (77 degrees F.) 96 500 kv and for 50 degrees C. (122 degrees F.) 88 800 kv between conductors. Table XXII values for 25 degrees C. (77 degrees F.) confirm this.

Table E values for corona loss indicate that No. 0 copper conductors can, with 144 inch delta arrangement of conductors and 1000 ft. elevation be used at line voltages as high as 100 000 volts without excessive corona loss during stormy weather. At 100 000 volts and assuming a 25 degrees C. (77 degrees F) temperature during fair weather and storm conditions, the corona losses would be 0.1 kw per mile for fair weather and 6.5 kw per mile for stormy weather. If the transmission is single circuit 100 miles long and without branches, has an average altitude of 1000 feet and the storm condition existed throughout the length of the circuit, the power loss due to corona would be 6.5 × 100 or 650 kw. The capacity of such a circuit at 100 000 volts (see Table XX) would be roughly 15 000 kw at ten percent I^2R loss. The storm corona loss therefore would represent $\frac{650}{15000}$ or 4.3 percent. This, in addition to ten percent I^2R loss, would represent approximately 14 percent loss in transmission during the storm conditions.

In the above case it would probably be considered good engineering (so far as corona loss is concerned)

TABLE XXII—APPROXIMATE VOLTAGE LIMITATIONS RESULTING FROM CORONA

STRANDED COPPER CONDUCTORS

B & S No. and Circular Mils	Diameter in Inches	Elevation in Feet	3 Ft	4 Ft	5 Ft	6 Ft	7 Ft	8 Ft	9 Ft	11 Ft	13 Ft	15 Ft	19 Ft	25 Ft
			Limit in kilovolts between conductors 3 phase for various spacings X											
4	.232	Sea level	54	56	58	60	62	63	64	66	67	69	71	73
		1000	52	54	56	58	60	61	62	64	65	67	69	71
		2000	50	52	54	56	58	59	60	62	63	65	66	68
		4000	46	48	50	51	53	54	55	57	58	59	61	63
		6000	43	45	46	48	49	50	51	52	53	55	56	58
		8000	40	41	43	44	46	46	47	49	49	51	52	54
		10 000	37	38	40	41	42	43	44	45	46	47	48	50
		12 000	34	35	37	38	39	40	40	42	42	44	45	46
		14 000	32	33	34	35	36	37	37	39	39	40	42	43
3	.260	Sea level	59	62	64	66	68	69	70	72	74	76	78	81
		1000	57	60	62	64	66	67	68	70	72	74	76	79
		2000	55	58	60	62	63	64	65	67	69	71	73	76
		4000	51	53	55	57	58	59	60	62	64	65	67	70
		6000	47	49	51	53	54	55	56	57	59	61	62	64
		8000	43	46	47	49	50	51	51	53	54	56	57	60
		10 000	40	42	44	45	46	47	48	49	51	52	53	55
		12 000	37	39	40	42	43	44	44	46	47	48	49	51
		14 000	34	36	37	39	40	40	41	42	43	45	46	47
2	.292	Sea level	65	68	71	73	75	77	78	80	82	84	87	90
		1000	63	66	69	71	73	75	76	78	79	81	84	87
		2000	61	64	66	68	70	72	73	75	76	78	81	84
		4000	56	58	61	63	65	66	67	69	70	72	75	77
		6000	52	54	57	58	60	61	62	64	65	67	69	72
		8000	48	50	52	54	55	57	57	59	60	62	64	66
		10 000	44	46	49	50	51	53	53	55	56	57	60	62
		12 000	41	43	45	46	47	49	49	51	52	53	55	57
		14 000	38	40	42	43	44	45	46	47	48	49	51	53
1	.332	Sea level	72	76	79	81	83	85	87	89	91	93	96	100
		1000	70	73	77	78	80	82	84	86	88	90	93	97
		2000	67	71	74	76	77	79	81	83	85	87	90	93
		4000	62	65	68	69	71	73	75	77	78	80	82	86
		6000	57	60	63	65	66	68	69	71	73	74	77	80
		8000	53	56	58	60	61	62	64	65	67	68	71	74
		10 000	49	52	54	55	57	58	60	61	62	64	66	68
		12 000	45	48	50	51	52	54	55	56	58	59	61	63
		14 000	42	44	46	47	49	50	51	52	53	54	56	59
0	.373	Sea level	79	83	87	89	92	94	96	98	101	103	107	111
		1000	77	80	84	86	89	91	93	95	98	100	104	107
		2000	74	77	81	83	86	88	89	91	94	96	100	104
		4000	68	71	75	77	79	81	82	84	86	88	92	95
		6000	63	66	69	71	73	75	76	78	81	82	85	89
		8000	58	61	64	66	68	69	71	72	74	76	79	82
		10 000	54	57	60	61	63	64	66	67	69	70	73	76
		12 000	50	52	55	56	58	59	61	62	64	65	68	70
		14 000	46	49	51	52	54	55	56	57	59	60	63	65
00	.418	Sea level	87	91	95	98	101	103	105	109	111	114	118	122
		1000	84	88	92	95	98	100	102	105	107	110	114	118
		2000	81	85	88	91	94	96	98	102	104	107	110	114
		4000	75	78	82	84	87	89	90	94	95	98	101	105
		6000	69	73	76	78	80	82	82	87	89	91	94	97
		8000	64	67	70	72	74	76	77	80	82	84	87	90
		10 000	59	62	65	67	69	[illegible]	72	75	76	78	81	84
		12 000	55	58	60	62	64	65	65	69	70	72	75	77
		14 000	51	53	56	57	59	61	62	64	65	67	69	71
000	.470	Sea level	95	101	105	108	112	114	116	[illegible]	123	125	130	135
		1000	92	98	102	104	108	110	112	116	119	121	126	131
		2000	89	94	98	101	104	106	108	112	115	116	121	126
		4000	81	87	90	93	96	98	100	103	106	108	112	116
		6000	76	80	84	86	89	91	92	96	98	100	104	108
		8000	70	74	[illegible]	80	83	84	85	88	90	92	96	99
		10 000	65	64	72	74	77	78	79	82	84	86	89	93
		12 000	61	64	67	68	71	72	73	76	78	79	82	85
		14 000	56	59	61	63	66	67	68	70	72	73	76	79
0000	.528	Sea level	104	111	115	119	123	125	128	132	136	139	144	150
		1000	101	107	111	115	119	121	124	128	132	134	139	145
		2000	97	103	107	111	115	117	120	123	127	130	134	140
		4000	89	95	99	102	106	107	110	113	117	119	124	129
		6000	83	88	92	95	98	100	102	105	108	111	115	120
		8000	77	81	85	88	91	92	95	97	100	103	106	110
		10 000	71	76	79	81	84	86	88	91	93	95	99	103
		12 000	66	70	73	75	78	79	81	84	86	88	91	95
		14 000	61	65	67	70	72	73	75	77	80	82	84	88
250 000	.575	Sea level	112	118	124	128	131	134	137	142	145	149	155	160
		1000	109	114	120	124	127	130	132	137	140	144	150	155
		2000	104	110	116	119	122	125	128	132	135	139	145	149
		4000	96	102	107	110	113	115	118	122	125	128	133	138
		6000	89	94	99	102	105	107	110	113	116	119	124	128
		8000	83	87	91	94	96	98	101	105	107	110	114	118
		10 000	77	81	85	88	90	92	94	97	99	102	106	110
		12 000	71	75	79	81	83	85	87	90	92	94	98	102
		14 000	66	69	73	75	77	79	80	83	85	87	91	94
300 000	.630	Sea level	120	128	132	138	142	145	148	153	158	161	167	174
		1000	116	124	128	134	138	140	143	148	153	156	162	168
		2000	112	119	123	129	132	135	138	143	148	150	158	162
		4000	103	110	113	119	122	125	127	132	136	139	143	150
		6000	96	102	105	110	114	116	118	122	126	129	133	139
		8000	88	94	97	102	105	107	109	113	116	118	123	128
		10 000	82	88	90	95	97	99	102	105	108	110	114	119
		12 000	76	81	84	88	90	92	94	97	100	102	106	110
		14 000	70	75	77	81	83	85	87	90	93	95	98	102
350 000	.681	Sea level	127	135	141	146	151	155	158	163	167	171	178	186
		1000	123	131	136	141	146	150	153	158	162	165	172	180
		2000	119	126	131	136	141	145	148	152	156	160	166	174
		4000	109	116	121	125	130	133	136	140	144	147	153	160
		6000	101	108	113	117	121	124	126	130	134	137	142	148
		8000	93	100	104	107	111	114	117	120	123	126	131	137
		10 000	87	92	96	100	103	106	109	112	115	117	122	127
		12 000	81	86	89	93	96	98	100	103	106	109	113	118
		14 000	75	79	82	86	89	91	93	96	98	101	105	109
400 000	.728	Sea level	135	143	149	155	160	163	166	172	177	182	189	197
		1000	131	139	144	150	155	158	161	166	171	176	183	191
		2000	126	133	139	145	149	152	155	161	165	170	176	184
		4000	116	123	128	133	138	140	143	148	152	157	163	169
		6000	108	114	119	124	128	130	133	138	142	146	151	157
		8000	99	105	110	114	118	120	122	127	130	134	139	145
		10 000	92	98	102	106	110	112	114	118	122	125	129	135
		12 000	86	91	95	98	102	103	106	109	112	116	120	125
		14 000	79	84	87	91	94	96	97	101	104	107	111	116
450 000	.772	Sea level	141	150	157	162	167	171	175	181	187	191	198	207
		1000	136	145	152	157	162	166	169	175	181	185	192	200
		2000	132	140	146	151	156	160	163	169	174	178	185	193
		4000	121	129	135	139	143	147	151	156	161	164	170	178
		6000	112	120	125	129	133	137	140	145	149	153	158	165
		8000	104	111	116	119	123	126	129	133	138	141	146	153
		10 000	97	103	108	111	115	117	120	124	128	131	136	142
		12 000	89	95	100	103	106	109	111	115	119	121	126	132
		14 000	83	88	92	95	98	101	103	106	110	112	116	121
500 000	.815	Sea level	146	156	163	170	174	179	183	189	195	199	207	216
		1000	141	151	158	164	169	173	177	183	189	193	200	209
		2000	136	146	152	158	163	167	171	176	182	186	193	202
		4000	125	134	140	146	150	154	158	162	168	171	178	186
		6000	117	125	130	136	137	143	146	151	156	159	166	173
		8000	108	115	120	125	128	132	135	139	144	147	153	159
		10 000	100	107	112	117	119	123	126	129	134	137	142	148
		12 000	93	99	103	108	110	114	116	120	124	126	131	137
		14 000	85	91	96	100	102	105	107	111	114	117	121	127
750 000	.998	Sea level	172	183	192	200	205	211	216	224	230	236	246	257
		1000	166	177	186	193	198	204	209	216	223	228	238	248
		2000	160	171	180	187	191	197	202	209	215	220	230	240
		4000	145	157	165	172	176	181	186	193	198	203	212	221
		6000	137	146	153	160	164	168	173	179	184	188	196	206
		8000	127	135	141	148	151	155	160	165	170	174	181	190
		10 000	118	126	132	137	141	145	148	154	158	162	169	176
		12 000	109	116	122	127	130	134	137	142	146	150	156	163
		14 000	101	107	113	117	120	124	127	131	135	139	145	150
1 000 000	1.152	Sea level	192	205	216	224	231	237	243	252	260	267	277	290
		1000	186	199	209	217	223	229	235	244	252	258	268	280
		2000	179	191	202	209	215	221	227	235	242	249	258	271
		4000	165	176	185	193	198	204	209	217	224	230	238	250
		6000	153	164	173	179	185	190	194	202	208	214	222	232
		8000	142	151	159	165	170	175	180	186	192	197	205	214
		10 000	132	141	148	154	159	163	167	173	178	183	190	199
		12 000	122	130	137	142	147	151	154	160	165	169	176	185
		14 000	113	120	127	132	136	139	143	148	153	157	163	170

SOLID COPPER CONDUCTORS

B & S No. and Circular Mils	Diameter in Inches	Elevation in Feet	3 Ft	4 Ft	5 Ft	6 Ft	7 Ft	8 Ft	9 Ft	11 Ft	13 Ft	15 Ft	19 Ft	25 Ft
4	.204	Sea level	51	54	56	58	59	60	61	63	64	65	68	70
		1000	49	52	54	56	57	58	59	61	62	63	66	68
		2000	47	50	52	54	55	56	57	59	60	61	63	65
		4000	44	46	48	50	51	51	52	54	55	56	58	60
		6000	41	43	45	46	47	48	49	50	51	52	54	56
		8000	37	40	41	42	43	44	45	46	47	48	50	51
		10 000	35	37	38	40	40	41	42	43	44	44	46	48
		12 000	32	34	35	37	37	38	39	40	40	41	43	44
		14 000	30	32	33	34	[illegible]	35	36	37	37	38	40	41
3	.229	Sea level	57	60	63	64	65	67	68	70	71	73	75	78
		1000	55	58	61	62	63	65	66	68	69	71	73	75
		2000	53	56	59	60	[illegible]	62	63	65	66	68	70	73
		4000	49	51	54	55	56	57	58	60	61	63	64	67
		6000	45	48	50	51	52	53	54	56	57	58	60	62
		8000	42	44	46	47	48	49	50	51	52	54	55	57
		10 000	39	41	43	44	44	46	46	48	49	50	51	53
		12 000	36	38	40	40	41	42	43	44	45	46	47	49
		14 000	[illegible]	35	37	37	38	39	40	41	42	43	44	46
2	.258	Sea level	62	66	68	70	72	73	75	[illegible]	79	80	83	86
		1000	60	64	66	68	70	71	[illegible]	[illegible]	76	77	80	83
		2000	58	61	63	65	67	68	70	72	74	75	78	80
		4000	53	[illegible]	58	60	62	63	64	66	68	69	71	74
		6000	49	52	54	56	[illegible]	58	60	[illegible]	63	64	66	69
		8000	[illegible]	48	50	[illegible]	53	54	55	57	58	59	61	63
		10 000	[illegible]	45	46	48	49	50	[illegible]	53	54	[illegible]	57	59
		12 000	39	42	43	44	45	46	47	49	50	51	53	54
		14 000	[illegible]	[illegible]	40	41	42	43	44	45	46	47	49	50
1	.289	Sea level	[illegible]	72	75	77	79	81	83	85	87	89	92	95
		1000	[illegible]	[illegible]	[illegible]	74	76	78	80	82	84	86	89	92
		2000	[illegible]	[illegible]	[illegible]	72	74	76	[illegible]	79	81	83	86	89
		4000	[illegible]	62	64	66	68	69	71	73	75	76	79	81
		6000	[illegible]	[illegible]	[illegible]	61	63	65	66	68	69	[illegible]	73	76
		8000	[illegible]	[illegible]	[illegible]	[illegible]	58	60	[illegible]	63	64	[illegible]	68	70
		10 000	[illegible]	[illegible]	51	53	54	[illegible]	57	[illegible]	[illegible]	[illegible]	63	65
		12 000	[illegible]	[illegible]	47	[illegible]	[illegible]	[illegible]	52	54	55	56	58	60
		14 000	[illegible]	[illegible]	[illegible]	[illegible]	46	[illegible]	49	50	51	52	54	56
0	.325	Sea level	75	79	82	85	87	89	91	94	96	98	102	105
		1000	72	76	79	82	84	86	88	91	93	95	98	102
		2000	70	74	76	79	81	83	85	88	90	92	95	98
		4000	64	68	70	73	75	76	78	81	82	84	88	90
		6000	60	63	65	68	69	71	73	75	76	78	82	84
		8000	55	58	60	62	64	66	67	69	71	72	75	77
		10 000	51	54	56	58	60	61	62	64	66	67	69	72
		12 000	47	50	52	54	55	56	58	60	61	62	65	67
		14 000	44	46	48	50	51	52	53	55	56	58	60	61
00	.365	Sea level	83	88	91	94	96	98	100	104	106	109	112	116
		1000	80	85	88	91	93	94	97	100	103	105	108	112
		2000	77	82	85	88	90	92	93	97	99	102	104	108
		4000	71	75	78	81	82	84	86	89	91	94	96	100
		6000	66	70	73	75	77	78	80	83	85	87	89	92
		8000	61	65	67	69	71	72	74	76	78	80	82	85
		10 000	57	60	62	64	66	67	68	71	72	75	77	79
		12 000	53	56	58	59	61	62	63	66	67	69	71	73
		14 000	48	51	53	55	56	57	59	61	62	64	66	68
000	.410	Sea level	[illegible]	96	100	103	106	109	111	114	117	120	124	128
		1000	88	93	97	100	102	105	107	110	113	116	120	124
		2000	85	90	93	96	99	102	103	106	109	112	116	120
		4000	78	82	86	88	91	93	95	98	100	103	107	110
		6000	73	[illegible]	80	82	84	87	89	91	93	96	99	102
		8000	67	[illegible]	74	76	78	80	82	84	86	88	91	94
		10 000	62	66	69	[illegible]	73	75	76	78	80	82	85	88
		12 000	58	61	63	65	67	69	70	72	74	76	79	81
		14 000	[illegible]	[illegible]	59	61	62	64	65	67	68	70	73	75
0000	.460	Sea level	100	106	110	114	117	120	122	126	129	132	137	142
		1000	[illegible]	102	106	110	113	116	118	122	125	127	132	137
		2000	93	[illegible]	103	106	109	112	114	118	120	123	128	133
		4000	86	91	[illegible]	98	100	103	105	108	111	113	118	122
		6000	80	85	88	91	93	96	97	100	103	105	109	113
		8000	74	78	81	84	86	88	90	93	95	97	101	105
		10 000	[illegible]	72	75	78	80	82	84	86	88	91	94	97
		12 000	[illegible]	[illegible]	70	72	74	76	77	80	82	84	87	90
		14 000	59	[illegible]	64	67	69	70	71	74	76	77	80	83

[illegible] are the disruptive critical voltage values for fair weather based upon a te[illegible] [illegible] conductors. Derived by Peek's formula: Kilovolts to neutral [illegible] M_o G_o δ [illegible] Spacing in inches. [illegible] Radius of conductor in inches. δ [illegible] Temperature in degrees F. B Barometer pressure in [illegible]

to operate the No. 0 copper conductors at as high a line voltage as 100 000 volts. If however, for other reasons, 120 000 is selected as the desirable operating voltage, then either a larger diameter copper conductor or an aluminum conductor having a greater diameter but an equivalent cross section to that of the No. 0 copper conductor should be selected.

TABLE E COMPARISON OF CORONA LOSS

For No. 0 Stranded Copper Conductors 105 500 cir. mil (diameter 0.373 in.) and equivalent Aluminum Conductors 167 800 cir. mil (diameter 0.501 in.) Conductor Spacing—Delta—144 in. Altitude 1000 feet—Barometer 28.9 inches. Calculated from formula (22)

Kilovolts		Corona Loss in Kw. per Mile for Three Conductors at 60 Cycles											
		Fair Weather—(Formula 22)						Stormy Weather—(Formula 22-A)					
		No. 0 Copper Radius 0.186 in.			Aluminum Radius 0.25 in.			No. 0 Copper Radius 0.186 in.			Aluminum Radius 0.25 in.		
Between Conductors	To Neutral	0° C 32° F $\delta = 1.05$ $e_0 = 60.5$	25° C 77° F $\delta = 0.967$ $e_0 = 55.7$	50° C 122° F $\delta = 0.892$ $e_0 = 51.3$	0° C 32° F $\delta = 1.05$ $e_0 = 77.5$	25° C 77° F $\delta = 0.967$ $e_0 = 71.5$	50° C 122° F $\delta = 0.892$ $e_0 = 66.0$	0° C 32° F $\delta = 1.05$ $e_0 = 48.4$	25° C 77° F $\delta = 0.967$ $e_0 = 44.5$	50° C 122° F $\delta = 0.892$ $e_0 = 41.0$	0° C 32° F $\delta = 1.05$ $e_0 = 62.$	25° C 77° F $\delta = 0.967$ $e_0 = 57.2$	50° C 122° F $\delta = 0.892$ $e_0 = 52.7$
100	57.8	0.0	0.1	0.2	0	0	0	0.3	6.5	11.3	0	0	1.1
110	63.5	0.3	2.3	6.0	0	0	0	7.8	13.3	20.3	0	1.7	4.6
120	69.2	2.6	6.7	12.8	0	0	0.4	14.8	22.6	32.0	2.0	6.2	12.6
130	75.1	7.25	13.9	22.6	0.0	0.5	3.8	24.4	34.6	46.5	6.7	13.7	23.2
140	80.8	13.8	23.3	34.5	0.3	3.7	10.1	35.8	48.7	63.7	13.9	23.8	36.4
150	86.7	22.4	35.5	50.2	3.3	9.9	17.7	50.2	66.	84.	24	37.2	53.3
160	92.4	35.0	49.8	67.7	8.7	18.7	32.2	66.	85	106.	36	53.	73.
180	104.8	66.0	89.0	115.0	24.3	47.3	69.5	108.	135	163.	72.	96.	125.

Note: At 25 cycles the losses would be $\frac{t_1 + 25}{t + 25} = \frac{25 + 25}{60 + 25} = \frac{50}{85}$ times the above table values. For conductors in a row (flat spacing) the corona loss would be reduced below the values for delta or triangular arrangement. For the higher voltages in the above table the conductor spacings would, in an actual installation, be greater than 144 in. (upon which basis the table values are given) thus giving actually less corona loss for the higher voltages than indicated by the table values.

Improvements in Contactor Types of Industrial Controllers

H. D. James*

THE essential part of any contactor is the contact and arc rupturing means. Whether the contact is closed by hand, by magnet or by an air cylinder, it is important that the contactor be able to interrupt the current and to operate repeatedly. The rolling contact is the most reliable type now in use, but an analysis of various designs indicates a considerable variation in performance.

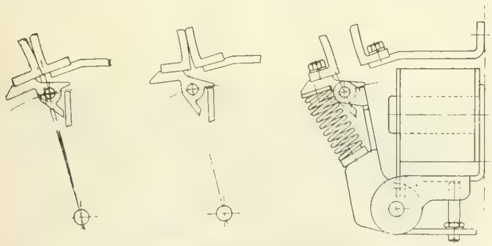


FIG. 1 ACTION OF ROLLING CONTACT

The rolling contact is shown in Fig. 1. Usually the movable contact member is attached to the armature of the magnet and mounted on an auxiliary pivoted member designated as the contact support. The pivot of this contact support approaches the stationary contact through the arc of a circle and the movable contact is tilted forward so that its tip comes in contact with the stationary contact tip. A further movement of the magnet armature causes the movable contact to roll against the stationary contact until the heels or bottom parts of the contacts are in engagement. An important part of the design is the relation between the pin, around which the contact support rotates, and the posi-

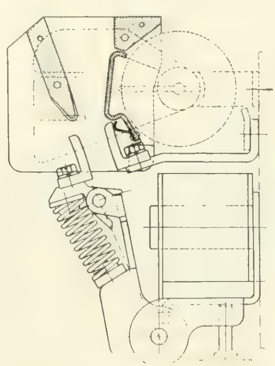


FIG. 2 SECTION THROUGH MAGNETIC BLOWOUT CONTACTOR WITH ARC SPLITTER

*Revised by the Author from a paper before the Assoc. of Iron & Steel Electrical Engineers, Sept. 1919.

tion of the contacts. The action of the contacts against each other cannot be a true rolling action, as the contact support hinge pin rotates through a circle and therefore its center moves up and down, due to this rotating action. The least amount of sliding is obtained when the moving contact center is located so that it moves at an equal distance on either side of the line drawn from the heel of the contact to the armature hinge pin. Even with this arrangement of centers there is always sufficient sliding action to keep the contacts clean. Excessive sliding action causes additional mechanical wear on the contact and in this way reduces their life. An endurance run on contactors having different amounts of sliding action makes the results of this wearing away of the contacts very evident.

FIG. 3—PRESSED STEEL MAGNETIC CONTACTOR WITH ARC SPLITTERS

Excessive sliding action is also disadvantageous from another point of view. If the surfaces of the contacts become rough, they have a tendency to lock together and prevent the sliding action. While this locking together is not absolutely positive, it has been found sufficient, in cases where the sliding action is excessive, to prevent the armature of the magnet from closing.

When a magnetic contactor is closed the contacts strike together with considerable force and there is a slight rebound. When the contact rebounds, it draws a small arc which softens the surface of the contacts at the point where they touched. If these contacts are per-

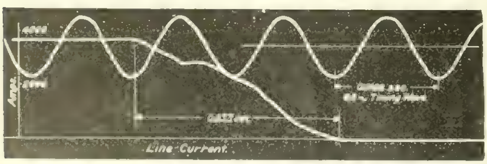


FIG. 5—ACTION OF 6600 VOLT MAGNETIC CONTACTOR

Tested with a 3000 volt direct-current short-circuit. Resistance of circuit, 0.941 ohms. Inductance of circuit, 23 millihenries.

mitted to come together at the same point after the rebound, there will be a decided tendency to weld or freeze, due to the softened metal parts coming into contact. This re-establishment of contact at the same point is prevented by the closing movement of the magnet armature. During the period of rebound, the armature has travelled closer to the magnet core and the center carrying the contact support is in a new position, so that contact is re-established at another place. This action was very nicely illustrated by a test. A magnetic contactor was connected to full load with a large condenser across the terminals. As a condenser produces a heavy discharge at the instant a contact is established, this property is frequently used for the purpose of welding small wires together. A condition was thus established which would materially increase the chances of welding at the instant of contact. The fact that this

FIG. 4—ACTION OF MAGNETIC BLOWOUT
At left—without arc splitter.
At right—with arc splitter—same load.

condition actually existed was demonstrated by closing the contacts slowly, which caused them to weld readily. When the contactor was closed by the action of the magnet, although a large number of operations were made, not a single weld was obtained, the rolling action being sufficient to prevent welding.

The closer the center of contact support is to the contact, the greater the lever action exerted by the closing means and therefore the greater ease with which a welded contact may be broken apart. This is of particular value in connection with manually-actuated con-

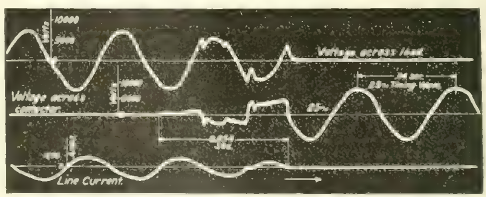


FIG. 6—ACTION OF 6600 VOLT AIR-BREAK MAGNETIC CONTACTOR
Tested with two contacts in series on 6600 volts, 950 amperes, 60 percent power-factor.

tactors, as these are more likely to be welded, due to improper operation. If the contact is closed by a cam, the operator can exert a very powerful force to break open any ordinary weld.

The life of the contacts and arc box depends upon the efficiency of the magnetic blowout. The function

of this blowout will be better understood by a brief description of the action which takes place in the arc box. The arc may be considered as consisting of a stream of positively and negatively charged gaseous particles or ions that travel rapidly from one contact to the other. This stream of rapidly moving ions constitutes the arc current between the contacts. Since it is a flexible conductor it can easily be stretched out lengthwise or

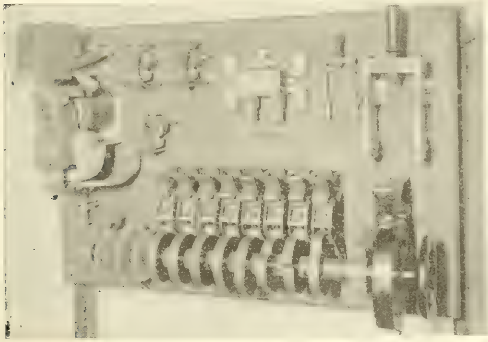
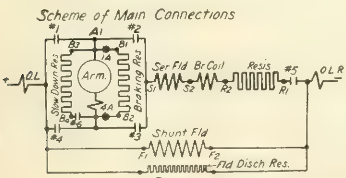


FIG. 7—CONTROLLER FOR A COLD ROLL MILL

The cam operated contactors are used for short-circuiting the armature resistance. The cam shaft is driven by a pilot motor mounted on the back of the panel. In this particular controller the last two contactors, which are connected in parallel for short-circuiting the entire armature resistance, have a continuous capacity of 800 amperes.

readily deflected. If a transverse magnetic field is applied to this conductor, the reaction between the conductor and the field will be similar to the action which takes place in a motor where a conductor carrying current is placed in a magnetic field. The conductor moves in the same direction as it would in a motor. This movement increases its length, which cools the arc gases and increases the resistance to the flow of current. The increased length makes it more and more difficult for the voltage across the arc to maintain the flow of ions, until finally the arc is ruptured. The length of the arc



Sequence of Contactors

Con	Forw'd Run			Off	Reverse S.D.	Run	
1	O	O					
2					O	O	O
3	O	O					
4					O	O	O
5	O	O			O	O	O
6					O		
1A				O			
4A				O			

FIG. 8—SIDE GUARD CONTROLLER

With this controller no accelerating contactors are used, the resistance in series with the armature being left permanently in circuit. This allows the side guards to travel up against the billet and jam the motor in this position with a limited amount of current. In going in the opposite direction, a slow-down resistance is used in shunt with the armature, as well as a dynamic brake resistance. This materially simplifies the usual form of reversing controller and requires only six contactors, two of which are provided with back contacts for dynamic braking.

depends upon the amount of current flowing when the arc is established, upon the voltage between the contacts and upon the stored energy in the circuit. The length of this arc may readily be influenced by the design of the arc box and blow-out field.

In addition to the ions which make up the flexible conductor, some stray ions accumulate in the arc box. If the distance between the contacts is small, the voltage between the contacts may cause these stray ions to

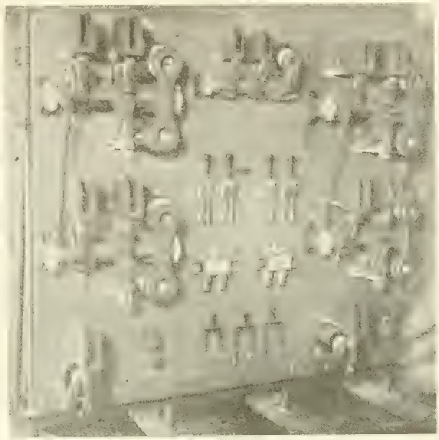


FIG. 9—DIAGRAM OF CONNECTIONS OF CONTROLLER SHOWN IN FIG. 8

re-establish the arc by forming a new flexible conductor. Oscillograph records show that sometimes the arc is re-established two or three times before it is finally interrupted. The re-establishment of the arc depends upon the design of the arc box and the separation of

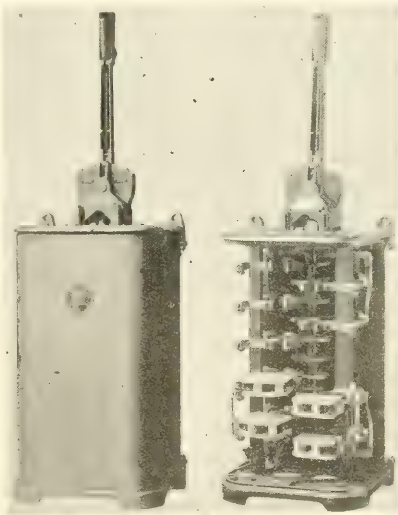


FIG. 10—CAM TYPE DRUM CONTROLLER WITH LEVER OPERATING HANDLE

This type of controller is particularly desirable on cranes and hoists, and most master switches and small controllers are equipped in this way.

the contacts. The higher the voltage, the greater the separation required. If two contactors are used in

series, there is much less liability of the arc re-establishing itself. The two breaks in series also assist in rupturing the arc, as they require the maintenance in series of two flexible conductors made up of ions. They also distribute the heating effect between two or more arc boxes.

To rupture an arc, it is necessary to lengthen the arc path, so as to increase the resistance, and therefore decrease the current, and at the same time, to cool the

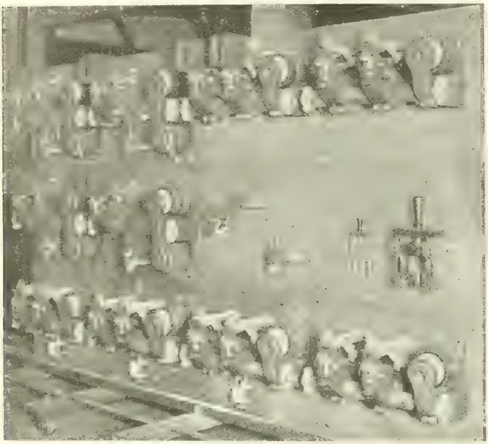


FIG. 11—LADLE CRANE CONTROLLER FOR TWO MOTORS GEARED TO THE SAME LOAD

Simultaneous operation of both motors is ensured by using double pole switches and connecting one motor to each pole, so that the time of switching for each motor will be the same. The accelerating relays are connected in the armature circuit of one of the motors, on the assumption that the motors are adjusted to divide the load. A number of devices have been tried for making single-pole contactors operate together, but the time element of the contactors changes, due to friction, dirt, etc., and the safest way is to tie the two circuits to the same magnet.

arc. The contacts should also be separated far enough to prevent a re-establishment of the arc, or two or more breaks should be used in series for this same purpose.

The cooling of the arc vapor and lengthening of the arc path is usually accomplished with a magnetic blowout. This lengthening and cooling may be materially assisted by interposing barriers or arc splitters in the path of the arc, Fig. 2. The ions, which maintain this arc stream, are not only cooled and discharged by contact with the sides of the arc box and the surrounding air, but are also cooled by coming in contact with these arc splitters. The length of the arc is also materially increased while it is still under the influence of the blowout field, by stretching it across these arc splitters. The projection or throw of the arc beyond the edge of the arc box is therefore decreased and much greater energy can be broken in the same size of arc box. If the arc extends a considerable distance beyond the edge of the arc shield, it ceases to be under the influence of the magnetic field and may continue to hang on for an appreciable length of time. The burning on the contacts and arc box for any given current depends upon the length of time the arc is maintained. The further the arc must travel in order to be ruptured, the greater the time of burning. By using these arc splitters, the arc is extinguished more quickly and therefore the amount of burning is decreased.

The material of which the arc shield is made, bears an important relation to the duration of the arc. Many asbestos compounds, now in the market, contain a binder, which is fused by the arc and forms a conducting skin on the side of the arc box. Tests made with certain well-known asbestos compounds showed that after the arc has been ruptured several times, the time of rupturing was materially increased, the amount depending upon the design of the box. It is therefore very desirable to construct arc boxes of material which does not form this conducting skin. The more refractory the material, the greater the life of the arc box. In a number of cases carborundum has been molded in the arc shield directly opposite the points of the contact, but it is not a good insulator and cannot be depended upon alone for the necessary insulation in high-voltage boxes.

Contactors using these arc splitters are shown in Fig. 3. These are made of pressed steel which reduces the weight of the armature to a minimum and reduces the magnetic lag, so that the contactors close and open more quickly than cast iron contactors. In addition to this quick operation, the center, around which the contact support rotates, is very close to the contacts, giving a quick rolling action.

Improvements in arc rupturing means are apparent in the design of the 6600-volt airbreak contactor illustrated in Fig. 4. A very interesting test was made on this contactor by causing it to rupture a 3000 volt direct-current circuit carrying 3750 amperes and an inductance of 23 millihenries. The oscillograph records of this test are shown in Fig. 5. The oscillograph shows that the circuit was ruptured in 0.033 second

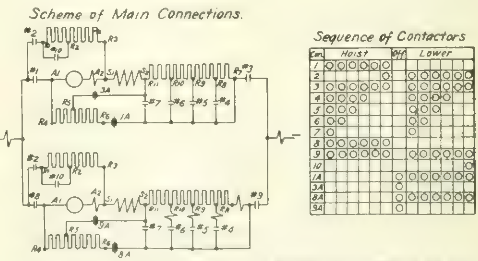


FIG. 12—DIAGRAM OF CONNECTION OF CONTROLLER SHOWN IN FIG. 11

and that the arc did not reform. The entire circuit was broken on one contactor a number of times without any apparent distress or liability of failure. This same contactor was tested on a 6600 volt alternating-current circuit using two breaks in series. As shown in Fig. 6, the rupture took place in 0.054 second. In making rupturing tests on alternating-current, care should be taken to see that the tests are made at a low power-factor. If the power factor is 100 percent, the current

passes through zero at the same time that the voltage is at zero, and it is easy to extinguish the arc. If the power-factor is 50 percent or less, the current passes through zero while the voltage is close to maximum, and is available for re-establishing the current before the gases have an opportunity to cool down.

Where a large motor is started and stopped frequently, such as in hoist service, it is preferable to use an air break contactor. An oil immersed contactor forms carbon in the oil each time the circuit is broken; an accumulation of this carbon will ultimately interfere with the proper operation of the contactor. Each time the arc is broken, the heat is transmitted to the oil, which in turn must radiate it from the outside of the case or tank. Repeated opening and closing will very materially increase the temperature of the oil, so that it is necessary to have a tank of proper proportions to absorb and radiate this energy without raising the oil to a dangerous temperature. These limitations have usually led engineers to prefer the air break contactor for frequent operation.

High-voltage contactors have large and heavy arc shields, so that it is difficult to inspect or repair the contacts by removing the arc shields. They are sometimes provided with a detachable window in the side of the arc box, which can easily be removed for inspecting and repairing the contacts.

Next to the contact and magnet blowout, the operating coil of a contactor or the low-voltage coil of the manual controller is a very important item, which has been materially improved, due to better materials and better processes. The coil is wound on a central insulating tube. The winding consists of enamel wire with cotton woven between the layers. At the same time, a cotton washer is woven on either end of the windings. After the coil is wound, the insulating end washers are put in place and a terminal clip is soldered to the ends of the coil. Where the coil wire is small, flexible cable is attached to the end of the wire and, after wrapping around the coil several times, is soldered to the terminal. These terminals are held in place by tape on the outside of the coil. The completed coil is then impregnated with an insulating compound. After being thoroughly baked, it is dipped into a varnish and again baked. The varnish treatment may be repeated several times, depending upon the requirements. The gum used for impregnating must have sufficient elasticity so that the continual cooling and heating of the coil will not cause minute cracks in the insulation. The use of the cotton washers at either end of the windings is to absorb the impregnating gum and form a seal to prevent creepage from the windings to the core of the magnet through the joint formed by the end washers.

In order to test this insulation, coils of various sizes were impregnated with a new gum, which will be designated as "No. 3 gum"; other coils were impregnated with another well-known form of insulating compound which had previously been extensively used for coils. All the coils were placed in an oven which was maintained at 50 degrees C., while current was passed through the coils. Their temperature when measured by resistance, was 140, 160 and 180 degrees C. This temperature was maintained constant for 2000 hours. The older form of insulation deteriorated very quickly at 160 degrees C. and at 140 degrees C. it was in very poor condition at the end of 600 hours. The coils with the No. 3 impregnating compound remained operative at 180 degrees C. for 1600 hours. The 160 degrees C. coils were still in good condition at the end of 2000 hours, but after cutting them open the microscope showed that they were beginning to deteriorate. The coils having the No. 3 impregnating compound and operating at 140 degrees C. showed no signs of deterioration when cut open after the 2000 hour run. This compound has been used for several years with very good results. The absence of lead wires and the substitution of terminals makes the coils much easier to handle and store and eliminates the trouble due to breaking of leads.

Series coils may be impregnated in the same way, as they are subject to the same insulation breakdowns as shunt coils. The older forms of shunt coils would sometimes open circuit, due to vibration, but by using an impregnating compound which thoroughly penetrates all parts of the coil, this trouble has been eliminated. A modern shunt coil seems to be just as reliable as a well made series coil and very much easier to handle on account of the small connections. The writer believes that from now on, a preference will be shown for shunt coils because of their equal durability with a series coil and because they eliminate the heavy connections.

Standardization of Electrical Indicating Instruments

For Use With Radio Apparatus

G. Y. Allen

DURING the past ten years, the art of radio communication has advanced at a rate comparable with few other scientific achievements. The advent of a fuller understanding of the laws governing radio frequency phenomona brought with it a demand for instruments capable of measuring accurately the quantities dealt with. Engineers who have been connected with the development of electric power will distinctly remember the crudity of measuring instruments in the early days, and how serious a handicap such a state of affairs was. The art of radio communication has experienced a similar difficulty, and it is only within the past two or three years that desirable instruments for measuring certain quantities have been available.

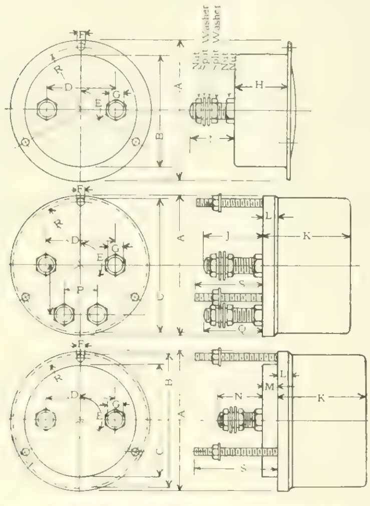


FIG. I STANDARDIZED DIMENSIONS OF INSTRUMENT CASES
The letters refer to Table I.

TABLE I.—DIMENSIONS OF INSTRUMENTS

Size	A		B	C*		F**	G	H	J	K		N	O	P	Q		R
	Max.	Min.	Exact	Max.	Deg.					Max.	Min.				Max.	Min.	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2¾	1½	3	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	2.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Dimensions [illegible] in the above table were not definitely specified. [illegible]

*[illegible] center line.

**Diameter [illegible] depending on which is used.

When the United States entered the European War, the burden of supplying and maintaining radio equipment for the entire contingent of vessels flying the United States flag, as well as equipment for high powered shore stations, was thrust upon the Navy Department. Contracts for a large number of sets were let, and it was not long before it was learned that the necessary instruments of a type suitable for radio work were not to be had. At this time, but two companies made instruments suitable for the severe service encountered by radio apparatus aboard ship and the lines of these two concerns did not overlap to any considerable degree. But one maker, therefore, made a suitable instrument of a given type, and it was absolutely impossible for him to supply all the instruments needed. The possibility of delay in production due to strikes, fires, etc., also had to be anticipated. The outcome of this situation was a number of conferences between instrument manufacturers and representatives of the Government, for the purpose of drawing up specifications for instruments which would be sufficiently standardized and still require the minimum number of changes on existing instruments. The initial step was taken by the Navy, when a conference was called in New York of representatives from the Westinghouse Electric & Mfg. Company, General

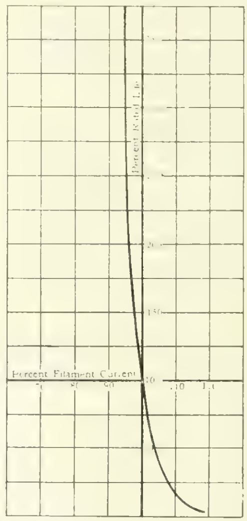


FIG. 2—RELATION OF FILAMENT LIFE TO FILAMENT CURRENT
The filament for which the data is given takes 2.5 amperes. Filaments taking 0.6 to 1.3 amperes are even more sensitive to current variations than that shown.

Electric Company, Weston Electrical Instrument Company, and the Roller-Smith Company. The representatives co-operated most loyally, and with their help preliminary specifications were drawn up for instruments which would be acceptable to the radio division of the Navy.

About this time the War Industries Board, in their effort to conserve material and to eliminate duplication of effort, called a conference of instrument makers and of government representatives from the various branches of the service, and subsequent Navy radio standardization of instruments was done in co-operation with this Board. Their recommendations, however, were more general than those required as a basis on which to make acceptance tests, and were made mostly from an economical and conservation standpoint. The Navy and the Army branches of the radio service, therefore continued their work of standardization as a subcommittee and final specifications were eventually drawn up covering the radio field. Subsequently, other

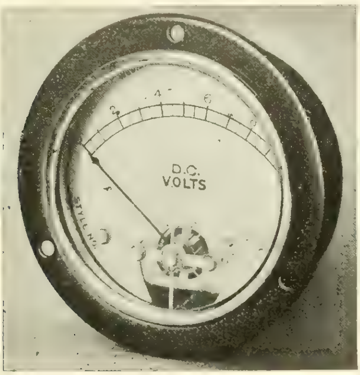


FIG. 3 FLUSH TYPE DIRECT-CURRENT VOLTMETER
Of the permanent magnet moving coil type. The diameter of the body is but two inches.

divisions of the Navy accepted certain of the instruments covered by the radio specifications and it is probable that the entire Navy and the Army will shortly be upon the same basis in buying electrical measuring instruments. Since the standards have been determined, at least two of the companies are in a position to supply many of the types and within the coming year all the instruments will be available from at least one company on a production basis.

PHYSICAL DIMENSIONS OF STANDARDIZED INSTRUMENTS

Fig. 1 gives the physical dimensions of instrument cases as decided upon by the Committee. These four sizes were arrived at after due deliberation and it is believed that they are sufficient to cover all needs. The 3½ in. size was retained only because instruments having a 2 9-16 in. diameter base were not available and it was impossible to await their development. It was the judgment of the Committee that the 3½ in. size would eventually be omitted, and the three remaining sizes would cover the field.

An attempt was made to standardize connecting stud locations on all front-of-board mounted instruments, but it was soon evident that this was impossible. Makers of existing instruments meeting the standard requirements with respect to outside physical dimensions had followed no standard in stud locations, and it was considered inadvisable, especially from a production standpoint, to require them to change to a uniform arrangement. The alternative for interchangeability among different makes was, therefore, decided upon, viz, boring a hole in the panel in back of the instrument such as is done for flush type of instruments. This

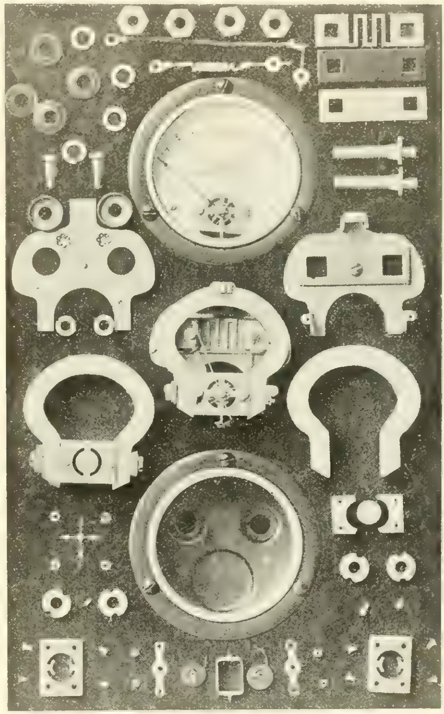


FIG. 4 EXPLODED VIEW OF INSTRUMENTS SHOWN IN FIG. 3

large hole would permit of any arrangement of studs being furnished and so instruments of any make could be used. Three holes or studs in the base of the instrument were specified for holding it to the panel, allowing the connecting studs to project through the large hole in the panel. Slack in the leads coming to the instrument was considered sufficient to provide for slight changes in stud locations when an instrument of one make was replaced by that of another.

The three types of cases specified are shown in Fig. 1. The semi-flush type of instrument was included, due to the fact that the maximum projection from the face of the panel was specified for front of board mounted

instruments, and some manufacturers were unable to fit their particular type of movement into this space. To provide for this contingency, a part of the movement can be enclosed in the part of the case projecting through the hole in the panel, a large hole being available in all panels as explained above.

CLASSES OF INSTRUMENTS

As far as measuring instruments are concerned, radio apparatus may be divided into three classes, as follows:—

1—Receiving sets and vacuum tube transmitters having ranges up to 30 miles.

2—Spark transmitters varying in input capacity from 0.5 to 10 kw.

3—High powered transmitters, comprising arc transmitters, high-frequency alternators, timed spark sets, etc.

The instruments in Group *1* are very small and are generally of the flush type. These requirements are governed by the small size of the apparatus, and the demand for an instrument which will occupy a minimum amount of space. As vacuum tube transmitters are coming into use more and more for aircraft, lightness of weight is an additional factor. Instruments whose dimensions correspond to those listed under size *1* of Table I are, therefore, extremely well adapted to this field.

FIG. 5—DIRECT CURRENT AMMETER
Having base diameter of 4⅜ inches.

The instruments in Group *2* are somewhat larger in physical dimensions, due to the fact that the equipment with which they are used is larger and also due to the fact that the dials of the instruments must sometimes be read at a distance. For the 0.5 and 1 kw panel-type spark transmitters, now being generally used aboard cargo vessels, yachts, and other small craft, the instrument having a base diameter of 4⅜ in. will be most suitable. A larger instrument would necessitate a larger panel than would otherwise be needed, or the instruments would be unduly crowded. Instrument requirements for transmitters ranging in input power from two to ten kw are met by the instrument having a base diameter of about 7½ in. This size is coming into favor with power companies, and so necessitates little alteration in the way of cases, magnets, etc. to make it suitable for use with radio apparatus.

The instruments in Group *3* will probably be of 7½ in. approximate diameter, due to the fact that they will be mounted on panels whose size will in no wise be determined by the size of the instrument. It is possible, however, that the 4⅜ in. size may be used on some remotely-controlled circuits.

The physical sizes of instruments are of the greatest importance from the standpoint of interchangeability among the products of various manufacturers, and are at the same time most difficult to standardize, due to the fact that, especially in the smaller sizes, the cases are drawn from dies.

DIRECT-CURRENT INSTRUMENTS

Direct-current instruments are used in all the standardized sizes. The specifications mentioned above accept direct-current instruments operating on the D'Arsonval principle only, due to the great accuracy required, and also due to the necessity for uniformity, ruggedness and reliability. The reason for these requirements can be better grasped by considering the specific uses to which the various direct-current instruments are placed.

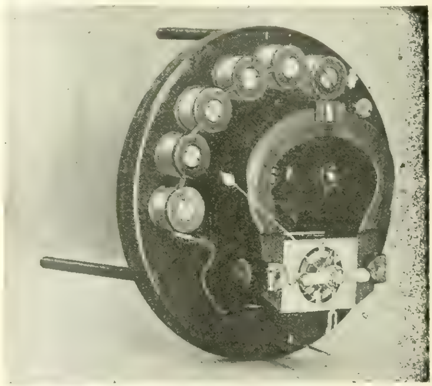
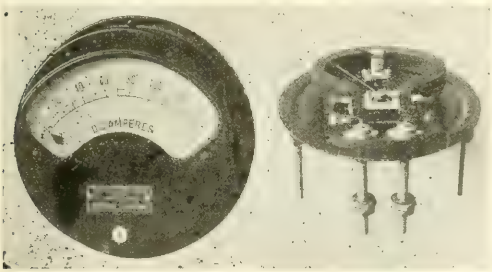


FIG. 6—REAR VIEW OF INSTRUMENT SHOWN IN FIG. 5
With cover removed.

The greater number of those in the 2 9-16 and 3½ in. sizes are used to measure the filament current, plate current and plate voltage supplied to vacuum tubes. Reference to Fig. 2 will prove the necessity of keeping the filament current within certain well defined limits and a reliable ammeter is necessary for this use. This need is augmented by the fact that two types of filaments are now in use in vacuum tubes, one operating at incandescence and one at a dull red heat, thus preventing judging current by the brilliancy, as used to be common practice. When the United States entered the war, the smallest instrument suitable for this work had a flange diameter of 3¼ in. which in some cases was sufficiently large to determine the size of audion control boxes, receivers, small transmitters, etc. In an effort

to cut down the size and still maintain the ruggedness and inherent accuracy of a permanent magnet instrument, the instrument shown in Figs. 3 and 4 was developed. This instrument is the smallest yet constructed, working on the D'Arsonval principle, its flange diameter being 2 9-16 in., and tests have shown that it sacrifices nothing in the way of accuracy. In the flush type of case, it is especially desirable for receiving sets, tube transmitters, etc., and may be had as an ammeter in ranges from 0.10 to 30 amperes, self-contained, and as a voltmeter up to 500 volts, when used with an external multiplier. Front of board mounted types are also available.

Direct-current instruments of the 4⅜ and 7½ in. size are used in Group *2* to measure the power supplied to the motor-generators of alternating-current spark sets and arc transmitters where direct-current only is available (such as aboard ship). As 500 volts or over are used with arc transmitters, instruments used on the high-voltage side of the motor-generator must be especially insulated. In order to protect the operating personnel from possible radio frequency high voltages, the cases are either carefully grounded, or provided with a special insulating cover. Due to the fact that the precision with which some of these quantities have to be measured governs the satisfactory operation of the entire transmitter, and as the operating personnel are far from being technically trained men, accuracy is one of the desirable qualifications and ruggedness and reliability are no less important. Instruments operating on the D'Arsonval principle are, therefore, specified for this service. Figs. 5 and 6 show the type of direct-current instruments having a base diameter of 4⅜ in.



FIGS. 7 AND 8—7.5 INCH DIRECT-CURRENT AMMETER

The requirements of Group *3* are met almost exclusively by the 7½ in. meters. This field includes all direct-current measurements, such as input power to direct-current motor generators, power at 500 volts or over to arc transmitters where special insulation is necessary, etc. Figs. 7 and 8 show external and internal views of instruments meeting these specifications.

All direct-current ammeters are specified to be provided with external shunts, except for use with the equipment of Group *1*.

ALTERNATING-CURRENT INSTRUMENTS

Practically all of the alternating-current instruments used at the present time with radio telegraph equipment are employed to measure current, voltage, power, etc. on the low voltage side of the step-up transformer. As most of the modern spark transmitters are of the high pitched spark frequency type, the majority of instruments for this class of work must be calibrated at about 500 cycles. In large shore stations, where alternating-current at commercial frequencies is supplied by power companies, the instruments required are outside of the field of purely radio instruments, and standard commercial equipment is suitable.

The instruments used in the 500 cycle circuit include a voltmeter, ammeter, wattmeter and frequency meter, and the specifications drawn up during the war call for them in both the 4⅜ and 7½ in. cases. Those in the 4⅜ in. cases will probably be used for sets whose input power to the transformer is from one-half to two kw, while those in the 7½ in. cases are applicable to sets from two kw up.

The difficulty of getting suitable alternating-current

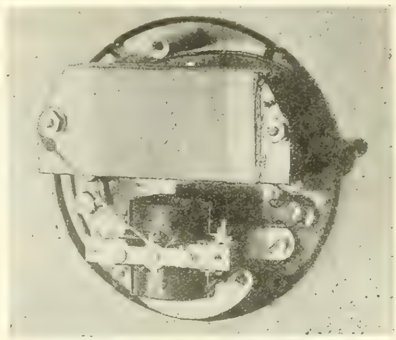


FIG. 9—INTERNAL VIEW OF ALTERNATING-CURRENT AMMETER
Having a flange diameter of 4⅜ inches.

instruments for radio service aboard ship was augmented by the fact that it is customary to vary the spark frequency as much as 20 percent under certain conditions. Yet accuracy and ruggedness were necessary, particularly the former, due to the fact that the 500 cycle circuit is worked near its resonant point, and unless certain conditions of voltage, current, frequency, number of gaps and various other variables are met, satisfactory operation cannot be obtained. Much credit is due therefore, to the various companies, who brought out instruments capable of giving the satisfaction which has been obtained. At present, 500 cycle instruments suitable for radio are in production in the 7½ in. cases only, but one or two concerns are practically ready to place them on the market in the 4⅜ in. cases. These small instruments are instruments of precision and the materials and workmanship are of the highest order. They can be used with the same confidence and the specified requirements for their accuracy are identical with the larger instruments.

The actuating principle for alternating instruments was not specified, as it was felt that, if the requirements regarding accuracy over the specified frequency and

temperature ranges were obtained and the instruments were sufficiently rugged, it was immaterial how the results were obtained. Accordingly, some manufacturers use the moving iron vane type, and the dynamometer principle is used by at least one manufacturer. Of these two, the dynamometer type is most free from error and, even in the 4⅜ in. size, the above concern has succeeded in obtaining sufficient operating torque to overcome any objection to lack of ruggedness. Figs. 9 and 10 show the internal construction of the type of instrument developed. The external appearance will, of course, be similar to Fig. 5.

Although the majority of spark transmitters up to 10 kilowatts bought by the Navy during the war were used aboard ship, yet in some instances, it was necessary to furnish this equipment for low power shore stations. Almost universally the power obtainable at these places was at 60 cycles. To facilitate the shipment of complete transmitters and also to minimize the number of types of instruments to be carried in stock,

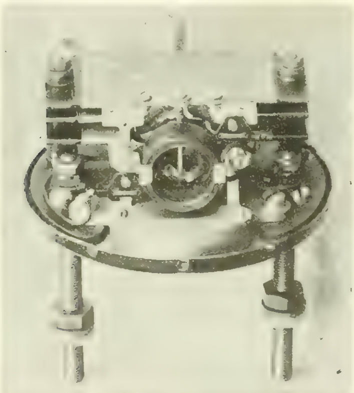


FIG. 10—SIDE VIEW OF INSTRUMENT SHOWN IN FIG. 9

it was felt advisable to stipulate that all 500 cycle instruments should be usable on 60 cycles. In the moving vane type of instrument this generally resulted in an error of three to four percent. To assure confidence of the personnel in the apparatus furnished, the specifications required that the dial of all instruments state a multiplying factor by which the readings should be corrected when used on 60 cycles instead of 500 cycles. Dynamometer types of instruments would, of course, not need this correction factor.

RADIO FREQUENCY INSTRUMENTS

The last group, electrically speaking, is the line of instruments developed to measure currents of radio frequency. Electrical engineers are more or less acquainted with an instrument which depends for its action upon the expansion of a hot wire or strip due to the heating set up by the current flowing through it and it is generally known that when properly constructed, the indications of such an instrument are practically independent of frequency, but the limitations of such an instrument are not so generally realized.

The first confronting problem is supporting the wire or strip so that the indications of the pointer will not be subject to errors due to changes of the temperature of the surrounding atmosphere. This condition has never been fully accomplished, but were it the only objection, a satisfactory instrument would undoubtedly result. Other elements however, enter into the irrational action of such an instrument.

In the first place, even in well constructed instruments, if the pointer is placed on zero, the current passed through the instrument and then the circuit be broken, the pointer will not return to zero. It may be found that no zero error exists after several hours, but it is obvious that an instrument whose indication shows such a lag is not satisfactory for practical use. Sluggishness of indicating is another objectionable difficulty. Again, the overload capacity of a wire or strip, which under normal load is worked at a high temperature, is very low. This feature is important because, due to resonance coming on rather suddenly during the tuning of a radio transmitter, an overload may be encountered and the instrument ruined before the operator can cut

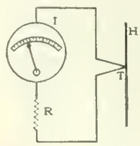


FIG. 11 — CONNECTIONS OF HIGH-FREQUENCY INSTRUMENT

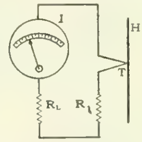


FIG. 12 STANDARDIZED CONNECTIONS

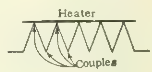


FIG. 13—MULTIPLE THERMO-COUPLES

I is the indicating voltmeter, *T* is the thermocouple and *H* the heater. R_2 is a series resistance in the voltmeter casing and R_1 a series resistance wound on the thermocouple base.

off the current. When an expansion type of radio frequency instrument has been damaged, due to burnout of the heating strip, it is a very tedious job even for an experienced workman to repair it. The above mentioned faults, together with its lack of ruggedness, caused the Committee on Standardization to eliminate the expansion type radio frequency instrument from those approved, and to approve only the thermocouple type.

The actuating force of this type is the voltage developed due to heating a thermocouple in close proximity to a strip or wire carrying the current to be measured, and whose temperature is caused to rise due to that current. With proper consideration given to details of construction, the temperature for a given current can be made practically independent of frequency. There are many advantages of such an instrument. In the first place, the indicating mechanism is composed of a millivoltmeter whose reliability and accuracy have been proven by years of service. This eliminates the great objection to expansion types of instruments whose movement is so fragile.

The use of a millivoltmeter in conjunction with a

thermocouple immediately suggests the analogy of the same instrument with a shunt for measuring direct-current, and development has now reached a point where the same flexibility has been obtained with millivoltmeters and thermocouples as is experienced with millivoltmeters and shunts. It is only recently that such a feat has been possible, however, and during the war, it was found necessary to calibrate each instrument with its thermocouple, and its use with other thermo-elements might cause as much as five percent error. An analysis of the problem will show the stages through which the instrument has passed. Fig. 11 shows a sketch of the connections between instrument and thermo-element in use during the war.

It is well known that it is impossible to make thermocouples to give uniform voltages with a given load and a fixed difference in temperature, and should this be possible, it would be impossible on a production basis to obtain this uniform difference in temperature for a given current through the heater. The customary procedure, therefore, was to let the voltage of the thermocouple come what it would and to adjust the resistance R within the instrument until the indication corresponded with the reading of a standard in the same circuit.

FIG. 14 BULB TYPE OF THERMOCOUPLE WITH PROTECTIVE CASING

The next step was to divide the series resistance between the instrument and the thermo-element. Fig. 12 shows the present arrangement. The thermocouple is generally mounted on a base of insulating material with its heater, and the resistance R_1 is wound on a part of this base. Resistance R_2 is within the instrument.

The calibrating procedure is to connect heater H to a high frequency circuit in which a standard ammeter independent of frequency is included, and connect a standard millivoltmeter of standard resistance to the voltage terminals of the thermo-element. The resistance R_1 is then adjusted to get proper deflection of this standard instrument. The millivoltmeter is likewise calibrated for a given voltage for full scale deflection, and its resistance is adjusted to be the same for all instruments. Now with a given current through the heater, all thermocouples generate at their terminals a definite voltage for a given instrument current, and as the millivoltmeters are adjusted to a uniform resistance, and show full scale deflection for a given current through the moving coil, it follows that millivoltmeters and thermo-elements may be interchanged with no sacrifice in accuracy. The thermocouple is the item subject to damage by overload, etc., and the advantage to be gained by merely removing the damaged couple from the circuit, and substituting a new one with no sacrifice in accuracy, is obvious, especially aboard ship.

Again, it is frequently desirable to use one indicating instrument to measure the current in various circuits, and the thermocouple interchangeable feature lends itself well to these requirements. Thermocouples can be placed in any of the numerous antenna circuits aboard ship, and as the couple is always in the ground lead, potential leads can be run to a distributing switch and the current in any circuit can be measured on the one instrument by merely turning the switch to the proper point.

In the British Navy, where expansion types of instruments are exclusively used, an attempt is made to get the same effect by using current transformers, but any one acquainted with radio frequency currents will immediately appreciate the difficulty of obtaining a transformer whose ratio can be predicted and which will have a constant ratio over the wide range of radio frequency used. The practice of the United States Navy has universally been to encourage the development of standardized thermo-couples and voltmeters.

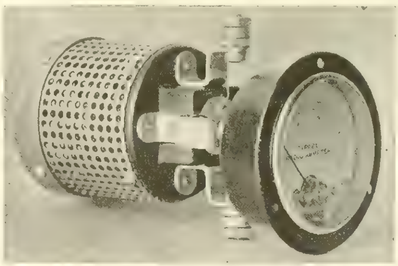


FIG. 15—RADIO FREQUENCY AMMETER
With bulb type of thermocouple.

Other advantages of thermocouples are their comparatively high overload capacity, their freedom from temperature errors, their ruggedness and their constancy of action.

The thermocouple described above is known as the "open" type on account of the fact that, except for protection from swiftly moving air currents, it is exposed to the atmosphere. Such an instrument works very well when the current to be measured is one ampere or above. Below this value, the heat conduction from the hot junction is so rapid that it is difficult to obtain the necessary potential in the couple unless a heating strip of objectionable resistance is used. To overcome the difficulty, the bulb or enclosed type of couple has been brought out by the Westinghouse Electric & Mfg. Co. This type of instrument sacrifices nothing in speed of response and its overload capacity is in no wise jeopardized. It has been made in ranges as low as 36 milliamperes for full scale deflection with re-

markably low power consumption. It is therefore, ideally suited for use with wave meters, and in other oscillating circuits of low power where the power consumed in the ordinary instrument is an appreciable part of the whole. At the present time, the decrement of a wave meter circuit is almost entirely dependent on the resistance of the thermocouple in the circuit and the demand for a wave meter with lower decrement than now exists can only be met by the use of a measuring instrument requiring less operating power. The present bulb type of couple requires about one-half the amount of power that the open type requires to give full scale deflection for 100 milliamperes range.

A photograph of the enclosed couple in its present stage of development is shown in Fig. 14. It is designed for mounting on the studs of the millivoltmeter in back of the panel. Fig. 15 shows the couple attached to the studs of one of the instruments listed under size *1* of Table I.

CAUSES OF FAILURE IN PAST DESIGNS

It will be interesting to discuss some of the pitfalls encountered in preliminary designs of thermocouples. In defense of some of the defective instruments whose faults might have become apparent had proper tests been made, it must be remembered that much of the development was done under pressure and that production was uppermost in everyone's mind at the time.

A defect which caused much anxiety, due to the fact that many instruments were bought before it was discovered, was the result of an attempt to obtain sufficient voltage across the terminals of the thermocouple element to permit the use of the then existing millivoltmeters. Multiple thermocouples were resorted to, the hot junction of each couple being placed in close proximity to the heating wire, and all couples were connected in series. This is illustrated in Fig. 13. In order to get efficient heat conduction from the heater to the junctions it was necessary to have intimate mechanical contact, and at the same time it was necessary to insulate each hot junction from the heater to prevent short-circuiting the couple. This was in one instance accomplished by the use of sodium silicate, baked on. In the particular instance, the couple was formed by very fine copper wire and a resistance alloy. After this instrument had been subjected to sea air for several days, the copper of the thermojunction became entirely oxidized, and the alloy showed signs of severe corrosion. The inference drawn was that the hygroscopic qualities of the sodium silicate were the cause of the corrosion. A spar varnish was finally baked on over the sodium silicate, and better results were obtained.

A noticeable, though unimportant, property of some types of thermocouple instruments was an appreciable error on direct-current. This is only incurred on single element couple instruments where the junction is electrically connected to the heater, and is due to the slight direct-current drop across the hot junction, on account of the impossibility of obtaining contact in one point. This feature is unimportant when the instrument is used at any frequency alternating-current because the average current through the heater in any direction is zero.

CONCLUSION

The work on standardization of indicating electrical measurements, as outlined above, and which was brought about by the urgent demands of the Great War, should have a valuable and lasting effect. Concessions were made willingly by competing manufacturers, and all thought of individual benefit was made subservient to the paramount issue of winning the war. The benefits which the combatant arms of the Government enjoyed as the result of standardization are now available to all having need for electrical measuring instruments. These benefits have an equal bearing on the manufacturer and consumer and it is sincerely to be hoped that the initial program based on such broad principles will be faithfully carried out in future developments.

A Problem in Three-Wire Distribution from Rotary Converters

L. Dorfman

THE EFFICIENCY of three-wire distribution frequently makes it desirable in connection with rotary converters, as well as with direct-current generators. In some instances, however, the addition of the third wire will introduce more or less difficult problems, which are apt to be of a practical rather than of a theoretical nature.

Consideration of some of the peculiarities of rotary converters will explain why such problems are often difficult of solution. In the first place, a rotary converter is a mechanical device for changing the form in which electrical energy is to appear. To be able to perform this function properly and efficiently an accurately balanced design should be employed. In a good design, this means quite a sensitive machine, and slight irregularities in the auxiliary apparatus may cause considerable trouble, because of unbalancing, with consequent loss in efficiency and performance. These facts also determine the accuracy necessary in the design of the transformers which deliver power to the converter. In fact, the reactances in the various phases of the transformer windings must be of substantially the same value, if trouble is to be avoided. Naturally, all of these matters have a direct bearing on the use of a third

or neutral wire, especially where unbalancing is apt to result from its use.

One case that may involve some difficult problems of transformer design is that of two-phase to six-phase transformation when it becomes desirable to connect the direct-current neutral, or third wire, into the alternating-current side. A better idea of this problem can be gained from Fig. 1, where the double Scott connection of transformers is shown. Two single-phase transformers, each having two secondary windings with taps provided for Scott connection, are connected to a two-phase source of power. One transformer consists of the primary coil, $P_{1\ 2}$, and the two secondary coils, S_1 and S_2. The secondary coils have taps brought out at 86.6 percent of the winding. The other transformer has a primary winding $P_{3\ 4}$, and the secondaries S_3 and

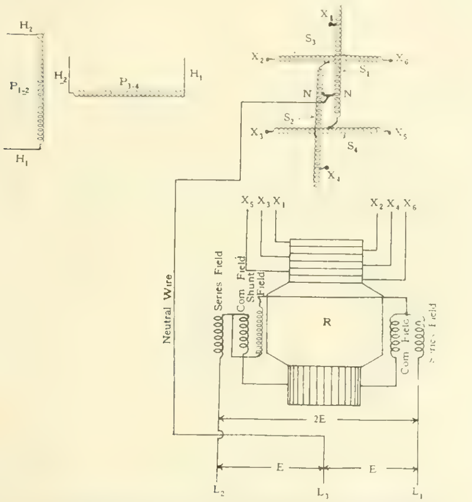


FIG. 1—TWO PHASE TO SIX PHASE TRANSFORMER CONNECTIONS
For bringing out a three-wire direct-current neutral from a rotary converter.

S_4. The secondary coils of this transformer have 50 percent taps brought out. By means of these taps, the double Scott connection is made, which delivers six-phase power to the converter through the six leads, X_1, X_2, X_3, X_4, X_5 and X_6, which are connected to the corresponding slip rings. The six-phase power having traversed the rotary converter R, is delivered at the commutator to the brushes. This direct-current power, after passing through the field coils, as shown, flows out over lines L_1 and L_2. Any unbalancing in the load between L_1 and L_2 will cause a current to flow in the third wire, or neutral, L_3. Naturally, this current must be returned to the system through the alternating-current side. The logical thing would be to bring out taps at the neutral points N of secondaries S_1 and S_2, and tie the neutral wire to this point, as shown in Fig. 1. The current would then divide equally among the six phases and no unbalancing would result. When considered from a practical standpoint, however, this simple scheme will not always work out, at least not without unbalancing. For example, it is generally impracticable to use more than ten turns in the secondaries of transformers for this service. In fact, fewer turns are more often the rule. In general, if the number of turns is so chosen that it is possible to bring out the 86.6 percent tap, then it is usually impossible to tap the neutral point, because it will occur at an inacessible fraction of a turn. Even

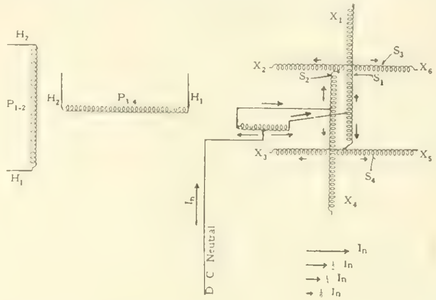


FIG. 2—BALANCE COIL FOR BRINGING OUT NEUTRAL
Where an exact 50 percent secondary voltage tap is impossible.

if taps are placed as near the neutral point as possible, there is a voltage unbalancing in addition to the direct-current unbalancing, which would be seriously objectionable.

When the conditions mentioned above are encountered, it is possible to provide means which will cause the current in the third wire to divide equally between the two taps (which are as near the neutral as possible) and at the same time keep down the alternating-current voltage unbalancing, by the use of a balance coil, such as is used for a similar purpose in three-wire direct-current generators. Fig. 2 shows the transformer connections as in Fig. 1, except that the balance coil B has been added. The neutral wire L_3 is connected to the center of the balance coil winding as

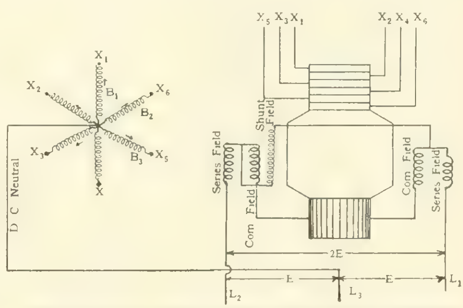


FIG. 3—USE OF THREE BALANCE COILS TO OBTAIN NEUTRAL
By connection to the converter sliprings.

shown. However, this scheme is not always entirely satisfactory because, while the balance coil divides the third-wire current equally between the two Scott connected groups, still the fact that the transformer taps are not quite at the neutral points will cause slight unbalancing in the windings. The extent of unbalancing

will depend upon how far the taps happen to be from the neutral. Usually, this unbalancing is not serious. This is clear when it is remembered that the neutral current divides in the teaser windings, S_1 and S_2, inversely as the number of turns between that point and the active turns in each direction. (By the active turns is meant only the 86.6 percent of the secondary windings S_1 and S_2). Thus, if the taps were exactly at the neutral point one sixth of the total neutral direct-current current would flow toward the 86.6 percent tap in each case and one third toward the 50 percent tap of the other secondaries S_3 and S_4. At the 50 percent tap of the other secondaries, S_3 and S_4, the one third current would then divide equally, one sixth going into each portion of the winding. It must be clear, then, that this equal division will not take place properly as long as the taps are not exactly at the neutral. However, the use of the balance coil tends to equalize the neutral current in each phase of the winding and gives balancing which is usually good enough.

Another method, quite different from the preceding in some respects, which insures correct balancing, but is slightly more expensive to install, is the use of balance coils which are connected directly to the slip rings of the converter, rather than to the transformer. This method, however, eliminates the necessity of trying to tap the neutral points of the transformer secondaries. Referring to Fig. 3, the three balance coils, B_1, B_2 and B_3 have their center points connected together, as shown, and the neutral or third wire, L_3, is joined to this point. The balance coil terminals are then connected to the respective slip rings in the order shown. In this way, the direct-current in the neutral is caused to divide equally, one sixth being directed to each phase. The flow of the direct-current is shown by the arrows, the assumption having been made that the unbalancing was such that it was flowing into the balance coils.

THE JOURNAL QUESTION BOX

OUR subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. The topics should be of general interest; information involving the specific design of individual pieces of apparatus is not supplied. Care should be used to include all data necessary for an intelligent answer.

A PERSONAL reply is mailed to each questioner enclosing a stamped, self addressed envelope as soon as the necessary information can be obtained. Anonymous questions cannot be considered. As each question is answered by an expert on the subject involved, and checked by at least two others, a reasonable length of time should be allowed before expecting an answer.

1815—WINDAGE—Can you tell me the law covering windage of similar style machines at the same speed but of different diameter?

J.E.MCH. (MICH.)

For machines of similar style running at the same speed, the windage varies approximately as the cube of the diameter. M.W.S.

1816—INSULATION OF SQUIRREL-CAGE ROTOR BARS—Have read in the June JOURNAL that it is unnecessary to insulate squirrel-cage rotor bars. Today a rotor was brought in for repairs. The report was—motor would not start, rotor was sizzling hot, burnt insulation off of bars due to standing still with current on. The rotor shows evidence of extreme heat and melting solder where sweated into end rings, stator reported O. K. The rotor bars are extra long, said to be for starting torque. It is a big job to dismantle and assemble the squirrel-cage. Now the question is if bars do not require insulation, why reinsulate, why dismantle? Could we ground the end rings (they are not grounded) and leave the burnt insulation in? Every one of the insulating cells does not appear burnt. A lamp burnt bright to ground. Why will not the motor start? It seems like it should even if insulation is burnt or bars grounded. Do you think the cause is elsewhere than in the rotor?

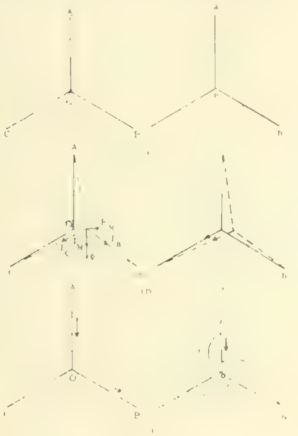
J.E.MCH. (MICH.)

Your question is not sufficiently detailed to enable us to say positively why the motor would not start. You do not even state whether it is a single-phase or a polyphase motor. Assuming the latter there are two plausible explanations. Either the motor was locked in the stand still position by an overload or by a frozen bearing or some other such difficulty; or the windings of one phase are open. With a star-connected or two-phase primary this would impress only single-phase current on the windings, which would cause the windings, both primary and secondary, to become exceedingly hot from the short-circuited single-phase current, but would produce no starting torque. A burned out fuse or a broken wire would easily cause this condition. There might be other explanations but this seems like the most plausible one. Even if the secondary insulation is all burned off, the rotor should start if the primary winding is in good condition. It is not really necessary to reinsulate the rotor bars, although insulation is more important in a motor of small number of poles (for example a 25 cycle, 2-pole motor), than it is on a motor having 6 or 8 poles or more. The only function of the insulation is to prevent current circulating through the iron and there is little tendency to do this where the flux path is short. It is not, however, advisable to try to operate this motor with the rotor bars loose in the slots. They should be tightly wedged mechanically or they will be liable to break off from vibration. The conductors should, of course, be resoldered onto the end rings wherever there is any possibility of poor connection, as poor contacts will cause further trouble. If the motor has been hot enough to melt the solder in the rotor, it would be advisable also to examine the stator carefully for the effects of overheating. C.W.K.

1817—STAR-INTERCONNECTED TRANSFORMER—To supply a three-phase, four-wire system with unbalanced loading, a star-star transformer is not permissible while a delta-star or star-interconnected-star transformer will maintain balanced line voltages and stable neutral. Please give a complete vector diagram for both primary and secondary sides, showing all voltages, currents and fluxes for each of the above connections i.e. star-star; delta-star; star interconnected-star; assuming say 25 percent out of balance current in the neutral wire and an average BH curve. S.A.S. (ENGLAND)

In the case of a star-star connected bank of transformers loaded unsymmetrically from lines to neutral on the secondary side, there are so many variables that it is impossible to give a quantitative answer. Fig. (a) shows the voltage vectors of the unloaded transformers *OA,OB,OC* being the primary voltages, and *oa,ob,oc* the secondary voltages. Assume now that a very small current could be drawn from secondary phases *ob* and *oc* without distorting the shape of the voltage vectors. This condition is shown by the dotted lines in Fig. (b). Such currents would cause currents I_B and I_C in the high-tension windings of the corresponding transformers. These currents in the high-tension windings would have to be supplied from line *A* through the winding *AO*. The resultant of the two currents is indicated in the sketch by I_R, which will be the current flowing in the winding *AO*. Since this current is not balanced by a current in the secondary winding of the same transformer, it will cause a flux in phase with itself, ϕ in Fig. b. This flux will cause a voltage E_R in the transformer *AO*, which will combine with the voltage *OA*. The points *A,B* and *C*, however, are fixed by the line voltages and cannot shift, therefore the neutral point will be shifted as shown. As soon as the neutral changes its position the voltages *OB* and *OC* change both their position and magni-

tude, and consequently the current in these two windings will change their position and magnitude. The final result will be that the point *O*, as the load on the two secondaries increases, will shift from its no-load position through some kind of a curved path until finally, for very heavy equal loads on these two phases, it will reach a point midway between *C* and *B*. The shape of this curve depends not only on the characteristics of the iron in transformer *A* but also on the power-factor of the load in phases *B* and *C*. The important thing to keep in mind concerning the star-star connection is that it should not be used unless the secondary load is balanced. The interconnected star is shown in Fig. c. It will be seen that a load connected between neutral of the secondaries and the line *B* will flow in transformer *OA* and also in transformer *OB* and that the corresponding primary currents will

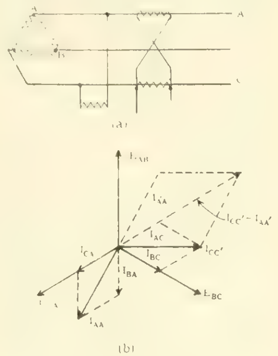


FIGS. 1817(a), (b) and (c)

both be balanced by secondary currents, so that there will be no tendency to shift the neutral. The delta-star connection when loaded on the secondary between lines and neutral amounts to three independent transformers connected across the three circuits of the primary line. Of course, there will be no tendency to shift neutral in this case
J.B.G.

1818—Tirrill Regulator Connections —Fig. (a) shows connections for series and potential transformers for supplying current to the alternating-current solenoid of a Tirril voltage regulator. The circuit supplying the transformers has a low power-factor, say around 60 percent. What would be gained by removing the series transformer whose current lags behind the current from the potential transformer (at 100 percent power-factor the current leads 30 degrees in one transformer and the other transformer current lags 30 degrees from that of the potential transformer)? The idea is to bring the currents acting on the alternating-current solenoid more nearly in phase. E.M. (N.Y)

These connections are used to secure the proper compensation for line drop. Such compensation requires that an e.m.f. be introduced into the regulator coils which shall be constantly proportional in amount and phase relation to the drop produced by the current. The vector diagrams in Fig. (b) show that, at unity power-factor, the current in the circuit which is fed by the two current transformers I_{AA}' and I_{CC}' is directly



FIGS. 1818(a) and (b)

in phase with the voltage *AC*. This resultant current from the current transformer, when lead through a suitable resistance and inductance, can be made to give e.m.f. components which are proportional to the ohmic and inductive components of the line drop. C.R.R.

1819—Power Input To Centrifugal Pump—Kindly explain why it is necessary to place a throttle in the discharge pipe when a centrifugal pump is operated on a smaller head than that for which the pump is designed, in order to prevent the motor driving the pump from being overloaded.
A.L.J. (PA.)

This can be understood by referring to the characteristic curves of a centrifugal pump, such as shown in Fig. (a). These are such in the usual pump that with a decrease of head the output will increase very greatly, so that the product of head and gallons per minute increases with a decrease of head. The extent of this action depends, of course, on the design of the pump, but the characteristics shown are the ones most commonly found. Such characteristic curves are given in almost any pump manufacturers catalogue. The whole subject is treated

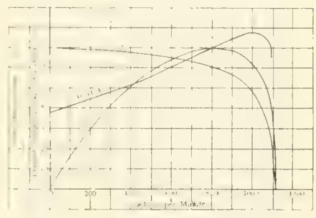


FIG. 1819(a)

at some length in an article on "Motor-Driven Centrifugal Pumps," by Mr. E. C. Wayne, in the Journal for March 1913, p. 228. The action of the throttle in the discharge pipe is of course to bring the effective head pumped up to normal and thereby reduce the output to that which the motor can properly supply. C.R.R

1820—Test Apparatus for Motors—Kindly suggest the best apparatus to use in testing one, two and three-phase, alternating-current motors of 110 and 220 volts, 60 cycles and from one to 35 hp, where the only available supply is 110 to 220 volt direct-current, three-wire system. Would a rotary converter and transformers do the work? If so, please specify style, connections, etc. Would also like information pertaining to a transformer to be used in conjunction with above apparatus for the purpose of a breakdown test? H.R.G. (N.J.)

We cannot recommend an inverted rotary converter as a source of power for this application as it would have poor speed regulation with varying power-factor load unless equipped with a special exciter. Also, the voltage could not be carried over the necessary

FIGS. 1820(a) and (b)

range for a saturation curve on an induction motor. To obtain good voltage and frequency regulation, we would recommend a motor-generator set. The 220 volt, direct-current motor should have a fairly flat speed curve. The generator should be three-phase, 220 volts. Three transformers should be used. These should be 220 volts on the high-voltage side, one having a 50 percent tap and the second an 86.6 percent tap when two are used for a Scott three-phase—2-phase combination. The low voltage side of the transformers should have two 110 volt coils which can be connected in either series or parallel for testing either 220 or 110 volt motors. For the breakdown insulation test, a portable two k.v.a. testing transformer can be purchased from any large electrical manufacturing company.
W.V.F.

1821—Static Discharge—What is the activity of a spark coil from an ordinary ignition system when, with the primary coil connected to a battery, you bring the end of the secondary close to a small nut or other piece of iron, which along with the rest of the system is thoroughly insulated from the ground and from its separate parts, and a spark continuously jumps to the nut. G.L.K. (ALBERTA)

A spark coil gives a high impulse of voltage which charges the nut or small piece of iron. When the voltage of the spark coil drops, the charged body discharges through the gap just as a cloud

discharges to earth through the lightning bolt. This is the same effect that is obtained when a screw driver or other

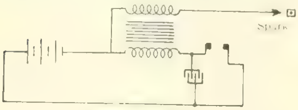


FIG. 1821(a)

piece of material is held near a conductor which is charged to 2200 volts or higher above ground potentials.

L.W.C.

1822—REACTANCE COILS TO PROTECT TURBINE-GENERATOR COUPLING—I have two turbo-alternators here that have been giving trouble with shearing the coupling bolts. They run at 3000 r.p.m., 440 volts, 50 cycle, 1230 amperes, three-phase. I wish to protect them with reactance coils. Would three percent reactance be enough? We have connected five feeder circuits. A 0.6 in., three-core lead-covered cable 440 volts, 1100 ft. long. An aerial 0.6 in. spaced 9 inches, 1000 ft. A 0.4 in. aerial, 1800 ft., 9 inch spacing all triangular. We have four, 350 horse-power motors, two on 0.6 in. cable and two on 0.6 in. aerial. The largest motor on 0.4 in. is 100 hp, all the others on this circuit range from 6 to 60 hp. All lines are fully loaded. Some of the short-circuits that occurred on or near the motors caused the lines to pull together near the power-house. The fourth circuit is feeding a step-up transformer 440 to 5000 volts through 0.4 miles of line, 200 kw is transmitted. The low-tension side cables are 90 ft. long. The fifth feeds a single-phase lighting transformer, 440 to 220 and 110 volts, 20 kw, 100 ft. We have no choke coils on any of these circuits except on the high-tension side of No. 6 circuit. We have multipath arresters and the consulting engineers say that they do not need any choke coils. Is this correct? Could I make chokers out of pieces of iron tubes slipped over the line switches and insulated from them, as I desire to put in chokers and have no suitable place to put them without a great expense and shutting down?

W.H.M. (AUSTRALIA)

The arrangement of generators and loads is understood to be as shown in Fig. 1. The calculated resistance, reactance and inpedance of one wire in each transmission line in series with one

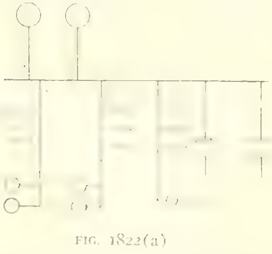


FIG. 1822(a)

phase of one generator is listed in Table I, together with the average of the three currents in the three wires of each line at the instant that short-circuit occurs near one of the motors. The kw load given in each case is the I^2R loss in line and generator for the current given. This is the load which is suddenly thrown on the machine at the time of short-circuit and one which might cause shearing of coupling bolts. Only in the case of line A is this load of sufficient magnitude to be considered.

TABLE I—SHORT CIRCUIT CURRENTS

LINE	A	B	C
Resistance in ohms 30° C	0.01515	0.0139	0.0352
Reactance in ohms 30° C	0.0273	0.0705	0.127
Impedance in ohms 30° C	0.0312	0.0718	0.131
Avg. inst. short-circuit current	10,500	4550	2500
Kw loss at 30° C — I^2R	5650	975	745

On a modern turbo generator of this capacity, the coupling would have twelve $\frac{15}{16}$ inch diameter bolts on a 7.5 inch bolt circle. On this basis, the maximum shearing force on the bolts for line A would be 3400 lbs. per sq inch, which is a very safe value. It would seem, therefore, that the couplings on these machines must have too few bolts, otherwise they could not be sheared off, even under the effect of an impact load. There is already sufficient reactance in the lines to limit the current to a safe value if the mechanical construction is correct.

S.L.H.

1823—CAPACITANCE MEASUREMENTS—In Pender's Handbook, first Ed., p. 183, the following statement is made: "In calculating the charging current, voltage drops, etc., in a single-phase or balanced three-phase transmission line it is sometimes convenient to consider the actual capacity between wires as made up of two capacities in series, each of twice the actual capacity between wires. This double capacity **** is called the capacity to neutral, since this capacity multiplied by the voltage to neutral, in either a single phase or a balanced three-phase line, gives the charge per wire ***.". 1. (a) Please explain what is meant by "capacity to neutral" and "voltage to neutral" of a single-phase line. (b) The statement "this capacity multiplied by voltage to neutral gives the charge per wire" is also not clear in view of the fact that the formula for charging current is usually given as,—

$$I = 2\pi f C E$$

2. Same handbook, tables pp. 187-190, gives "Capacity to neutral in microfarads **** of each wire of a single-phase or of a symmetrical three-phase line" with a footnote "The capacity between wires equals one-half the values given in this table". (a) Please explain the first statement by indicating what would be the relative readings of the ammeter in a test on a transmission line, when two phase wires only are energized, and when three phase wires are energized. Would the ammeter read the same in both cases?

L.C.P. (OHIO)

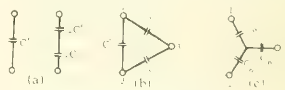
The tables for calculating the charging current as given in handbooks are based on the voltage between line and neutral and an equivalent capacity between line and neutral. On a single-phase system the voltage between line and neutral is one-half the line voltage; on the three phase system it is equal to $1/\sqrt{3}$ line voltage. With the single-phase case the equivalent capacity between line and neutral is twice the actual capacity between lines. Referring to Fig. (a), it will be seen that the charging currents are the same in either case, remembering the rule that condensers in parallel have a capacity equal to the sum of the separate capacities, and that the reciprocal of the capacity of the condensers in series is equal to the sum of the reciprocals of the separate capacities. For the balanced three-phase cases the conditions appear slightly different. Let the apparent capacity effects be represented by three condensers connected as shown on Fig. (b). These condensers might also be assumed to be as shown on Fig. (c) with C_n the capacity between the line wire and neutral. These two capacity arrangements are equivalent, when they give the same capacity between terminals. Let C represent the capacity between the terminals 1-2; 2-3; or 3-1. The equations connecting the various capacities can now be written as follows:

$$C = \frac{3}{2} C' = \frac{C_n}{2}$$

With balanced voltage of E per phase the charging current per wire is the same for Figs. (b) and (c) which gives,—

$$\sqrt{3}\, E\, 2\pi f C' = \frac{E}{\sqrt{3}}\, 2\pi f C_n,\ C_n = 3C'$$

Hence the equivalent capacity between line and neutral is equal to twice the capacity between wires. It will be observed that the capacity C_n between line and neutral might also have been defined as three times the capacity between lines as defined by C', in which case the capacity between lines would have the same meaning as in the single-phase case. To show how these relations may be applied, the values of charging current for a three phase line under various



FIGS. 1823(a), (b) and (c)

conditions of operation will be calculated. Suppose a three phase line composed of three 4/0 conductors spaced two feet apart and a mile long, supplied by a three-phase, 60 cycle, 20 000 volt system. Referring to Penders' handbook the charging current for the balanced three-phase system can be calculated as follows:—

$$I = \frac{20\,000}{\sqrt{3}} \times \frac{7.25}{10^6} = 0.0837 \text{ amperes}$$

For the single-phase case, that is, with the third wire removed, the charging current would be—

$$K' I = \frac{20\,000}{2} \times \frac{7.25}{10^6} = 0.0725 \text{ amperes}$$

If the third wire were left in place, but disconnected at both ends the charging current would be approximately the same as if the wire were removed.

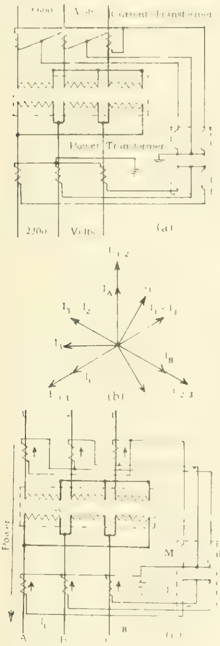
R.D.E.

1824—REVERSE POWER RELAY CONNECTIONS—A three-phase transformer, 6600 volts to 2300 volts, has three current transformers delta connected on the high-tension side, which is star connected, and three current transformers star connected in the low-tension side which is itself delta connected. The current transformers are

connected to the coils of a two pole "Instantaneous Reverse Power Relay" as shown, and the current transformers are grounded as indicated. (a) Upon inserting an ammeter in the ground wire, I found an appreciable current flowing. The phases show an unbalancing of from 10 to 20 percent due to single phase loads. Is this current mentioned influenced by the amount of unbalancing and just what is the circuit of this ground wire current? (b) What is the effect of moving the ground wire to a different corner of the delta? (c) Please show vectorially the conditions of the circuit assuming an unbalancing of 20 percent and 70 percent power-factor.

J.S. (CONN.)

Fig. (a) shows that one of the coils is connected to a "Z" connection, whereby the current would add vectorially to five amperes instead of 8.66 as in case of the other high-tension connections. Fig. (c) shows the proper connections



FIGS. 1824(a), (b) and (c)

to the relays. It is presumed that the current transformers on primary and secondary are so connected that, neglecting transformer losses, when five amperes flow in each of the primary current transformers, five amperes will likewise flow in each of the secondary current transformers. Since the power transformer is connected in star-delta, the current in lines *1*, *2* and *3* will be 30 degrees out of phase with the current in lines *A*, *B* and *C*. The current in line *A* will be in phase with voltage E_{1-2}, the current in line *B* will be in phase with the voltage between wires *2* and *3*, and so on. With the connections shown in Fig. (c), the current in coil *M* will be opposed by the current in coil *K*, and the current in coil *N* will be opposed by the current in coil *L*. However, in order to get the proper phase relations so that *M* opposes *K*, and *N* opposes *L* arithmetically, it was necessary to bring the current from the secondaries of the current transformers into phase by recourse to the delta connection of the current transformers on the primary side. Unfortunately, this latter procedure introduces the complication that the current in *M* and *N* will be on the order of 8.66 amperes against 5 amperes current in *K* and *L*. It is customary to overcome this difficulty by installing current transformers in the lines to coils *K* and *L* which will raise the current from 5 to 8.66 amperes. On the other hand, the current transformers in the secondary of the power transformer may be selected with a secondary ratio of 8.66 amperes, depending on whether these transformers are used exclusively for these relays or other instruments as well.

L.A.T.

1825—LIGHTNING PROTECTION FOR METERS—Considerable trouble has been experienced from polyphase 440 volt meter breakdowns due to lightning. Satisfactory arrester protection has not been found. Meters have been installed with a lighning arrester connected to each line wire on each side of the meter, and though the arresters were undamaged, the meter was entirely destroyed. The arresters were of a well known make and the expulsion type which are considered as satisfactory as any. There were no

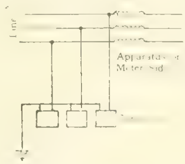


FIG. 1825(a)

choke coils used with the arresters. It is necessary to install a meter on a line as long as 2000 feet to register the loads of several motors. Do you consider it would pay to install choke coils with the arresters? Can you recommend a low-voltage choke coil of about 25 amperes capacity, also low-voltage arresters or a combination of both that are so arranged that they will not require a large space to install them in. Our steel cabinets are limited for space.

I.W.R. (KANS.)

We would suggest the use of a choke coil combined with a condenser type lightning arester, as shown in Fig. (a).

1826—SINGLE-PHASE MOTOR WINDINGS—I have a single-phase, rotating field, stationary squirrel-cage armature, 110 volt, 6.6 ampere, 60 cycle, split-phase starting, induction motor. The rotor is wound for four poles, having 48 slots on its face. The starting windings are wound 90 degrees, or 45 mechanical degrees to the running windings. The running coils are composed of four sets of coils; each set having 18, 16, 14, 12 and 10 turns, of No. 16 copper wire. The coils containing the greatest number of turns, are on the outside of the set with the smallest coil in the center. The largest coil spans 12 slots, in the field face, while the smallest spans 4 slots (including the two it is wound in). The starting coils are wound of No. 26 copper wire, and have four sets of coils with five coils per set. They are wound similar to the running coils with the coil of most turns outermost. The coils have 16, 14, 12, 10 and 8 turns of wire, with the largest coil spanning 12 slots (including the two it fills). These coils are connected (on both starting and running windings) so that a test for polarity with direct-current shows every adjacent pole reversed, i. e.; North, South, North and South. The leads of the running winding connect directly to slip rings, while the starting winding has a centrifugal cut out

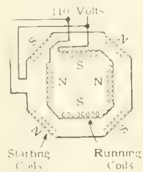


FIG. 1826(a)

switch in circuit. The field does not rub on the armature and the bearings are not tight. The slip rings are new and the brushes are in good condition and make good contact. Normal voltage is supplied to the field, and it is not loaded in any way. Due to burnt out windings the writer undertook to rewind this motor and followed the hand winding method using the above data on the number of turns, etc., but the motor will not run. Tests prove the windings are not grounded in any way. Could you advise me as to whether the number of turns are correct? Whether the polarity is correct? Also as to what is the cause of its non-operation? When voltage is applied and the field is in a certain position, it will start to rotate and move half a revolution, where it will stop and produce a loud humming. Hand rotating at any other position will be discouraged by strong brake effect.

E.W.MCC. (IDAHO)

The fact that the armature resists rotation by hand when in certain positions indicates that the secondary, i. e. squirrel-cage winding, is not of uniform resistance, but has a path of relatively low resistance and one of very high resistance. This could be caused by the heat deteriorating the contacts between certain of the bars and the end ring. This condition also indicates that, in addition to the defective squirrel-cage, the primary field is strictly single-phase and has no rotating component such as would be caused by the starting winding, because even though the secondary was defective, it would not cause a locking or resistance to motion if the primary was producing a rotating field, although it might not go up to full speed. We would suggest that the joints between the squirrel-cage bars and resistance rings be carefully resoldered and that the circuits of the main and starting winding be carefully checked to see that neither one is open. It is possible that an open circuit exists at the contact point of the starting switch and these circuits should be, therefore, checked from brushholder to brushholder and not simply from winding terminal to winding terminal. We see no discrepancies in the winding or connections as described.

G.H.G.

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

NOVEMBER 1919

Shop Organization

To keep down the expense and turn out the maximum amount of work with the least number of men, the shop force in charge of the upkeep of railway equipment should be thoroughly organized. Each group of men should be assigned certain duties for which they are held responsible by one man in charge, who in turn reports to someone higher up within the organization; thus avoiding repetition of work and confusion in carrying out orders and reporting troubles. By this means, the head of the organization can keep in close personal touch with all lines of his work through the directing heads of the various departments.

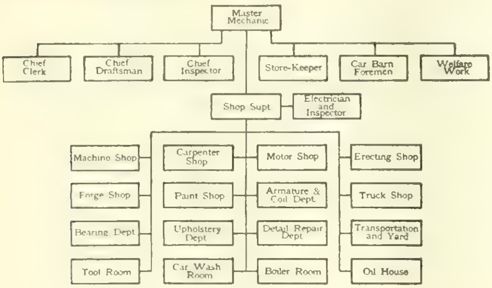


FIG. 1—TYPICAL ORGANIZATION CHART

In presenting the organization chart here shown, the object is to give a general scheme that can be used as a guide in building up an organization for handling economically the work of maintaining the equipment of a street railway company of average size. Smaller companies will find it advisable to condense this chart, while it may be necessary to make further subdivisions to meet the requirements of larger operating companies.

DUTIES OUTLINED

The Master Mechanic should be the directing head of the entire system, and through the channels of his immediate associates, issue all instruction and receive all information relating to the workings of the organization. All welfare work should come directly under his supervision.

The Shop Superintendent is responsible for the work of the electrician and inspector, and should have direct charge of all departments of shop work as follows:

DEPARTMENTS	WORK HANDLED
Machine Shop	All machine and bench work.
Forge Shop	Forgings, oxyacetylene and arc welding
Bearing Dept	Rebabbitting of bearings.
Tool Room	Care and repair of tools, gauges, etc
Carpenter Shop	All wood and cabinet work
Paint Shop	Painting and glass work
Upholstery Dept	Repair of seats and curtains
Car Wash Room	Cleaning and washing of car bodies.
Motor Shop	Reconstructing, repairing and testing of motors.
Arm. and Coil Dept	Rewinding and repairing of armatures, repair of commutator and field coils
Detail Repair Dept	Repair of controllers, grids, compressors, brushholders, registers, etc.
Boiler Room	Supply of heat, light and hot water
Erecting Shop	Assembling of car bodies on trucks and testing for service
Truck Shop	Reconstruction of trucks; wheel and axle replacements.
Transportation and Yards	Transportation of material between shops and car barns. Shop yard work.
Oil House	Storage for oil, grease and waste.

The work of each of the above departments should be in charge of a sub-foreman, who reports directly to, and receives his instructions from the shop superintendent.

Electrician and Inspector—Under the direction of the electrician and inspector comes the inspection and the electrical testing of all details and completed apparatus placed on the cars, both old and new. He should be held responsible for the proper working of all equipment on the repaired and overhauled cars.

Chief Clerk—The duties of the chief clerk should be to direct the general work of the office force and be responsible for accurate records of equipment maintenance, repairs, inspection, etc.

The Chief Draughtsman should be in charge of the drawing-room, keep records and files of all blue prints and drawings.

Chief Inspector—The duties of the chief inspector should be to keep in close touch with the equipment out on the road and to note conditions of cars and the equipment at the various car barns and inspection sheds.

The Storekeeper should be in charge of all supplies and repair parts used in all departments of the shop and at the various car barns. Records of material issued to all departments should be kept, and written reports submitted at stated intervals. He should also be in charge of all scrap material for whose storage adequate facilities should be provided. By a systematic inspection and segregation of all scrapped material there will be sufficient salvage to more than pay for this added expense.

The Car Barn Foremen should be in charge of all work connected with the cleaning, oiling, inspecting and light repairing of all equipments running out from their respective barns.

Welfare Work—A few suggestions for work to be considered under this general heading are:—

1—Provide first aid to all injured employees.

2—Establish and maintain a "Safety First" campaign.

3—Provide suitable lunch and wash room facilities.

4—Promote and encourage a spirit of co-operation between the various departments by having regular meetings of the heads of these departments for the interchange of ideas.

5—Establish classes for the instruction of the men in the fundamentals of the electrical equipment pertaining to their work.

6—Provide recreation rooms for the employees.

7—Encourage the men to express their ideas regarding their work by means of a suggestion box.

8—Plan and work with the men to arrange for social events outside of the regular working hours, such as entertainments, shop picnics, athletic meets, etc.

9—Cooperative buying for the employees.

JOHN S. DEAN.

The Electric Journal

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High-Speed Photography

The writer recalls that, when a boy, he looked with wonder and admiration at photographs purporting to be instantaneous, and read with still more wonder the statement that such photographs proved that motion was not continuous, but a process of translation from place to place by sudden jerks, separated by periods of rest. These periods of rest were reported to afford the photographer opportunity to slip in and take a picture surreptitiously. This theory did not make good, but rapid photography did, and passed from the initial stages of single, comparatively short exposure work to the moving picture, with its succession of short exposures which could be reproduced on the screen to simulate the original moving object.

When it comes to really high-speed work, however, the "movie" is hopelessly slow. Fifteen to thirty-five exposures per second do not mean much when the whole phenomenon is over in 0.01 second. In this issue Mr. Joseph W. Legg describes a camera capable of taking pictures at the rate of 3000 per second. Such a camera is comparable to the oscillograph in recording the details of transient electrical phenomena.

For some purposes, of course, such speed is not necessary, but for many of the extremely rapid changes in the configuration of visible forms the finely defined and well distinguished pictures Mr. Legg has produced are instructive, and a source of delight to the investigator or engineer. The steroscopic exposures obtainable, when properly mounted, give a view of what is occuring with unusual vividness, as the flame or object stands out in space, disclosing the shape in three dimensions. The neatness and elegance of the design, and the great increase of speed over any instrument previously built for making a series of separate successive exposures, makes it a notable advance in high-speed photography.

R P Jackson

Starters for Small Induction Motors

Protection of employees from injury and increase of production without a proportionate increase in production cost are the ever present problems confronting those responsible for the success of any business enterprise. The electrification of industries has produced remarkable results in this direction and in many cases has doubled the output from a given machine, while at the same time reducing the operator's duties, thereby permitting the concentration of his energies on the perfection of the process, with resultant improvement in the finished product. We frequently read of the remarkable results obtained by electric motor drive, but few appreciate the effect of the motor starter or controller upon the economies effected.

The development of systems of control and the perfection of control apparatus has been an important factor in the decision of industrial and mining engineers to replace the older forms of power with electric motors for the operation of the main rolls in steel mills, large mine hoists and similar applications. Large equipments of this nature have always been provided with devices for protecting the operator, motor and equipment, as such devices represented only a small portion of the total cost. However, for every motor installed of 1000 horsepower or larger, there are over 4000 smaller motors placed in service, varying in size from one-half to ten horse-power, which also should be equipped with controllers providing full protection to the operator, motor and equipment. Several years ago the cost of such protective devices was prohibitive, but now controllers providing these features are available at a reasonable cost and even the smaller motors should be protected.

In their article in this issue on "Manual Starters for Small Squirrel-Cage Induction Motors" Messrs. Applegarth and James discuss many features that should be considered when selecting a starter for a small motor, and show how these features provide safety to the operator, increase the output and lower the cost of production.

J. M. Curtin

Maintenance of Railway Equipment

The articles in this issue by Messrs. W. W. Cook and J. S. Dean are timely and will be read with great interest by railway maintenance men. Instructive articles on this important subject are entirely too few. Every encouragement should be given to railway men to record their experiences and practices on equipment maintenance, so that operators can have an opportunity to compare their own methods with those of others and, in this manner, develop the art of maintenance to a much higher plane than at present.

The general use of the passenger automobile has served, to some extent, to bring home to the minds of many people the fact that highly developed machinery, subjected to the stresses, vibrations and abuse that obtains on street cars or automobiles, requires constant scientific maintenance methods in order to avoid failures

in service and high repair expense, as well as disappointment and dissatisfaction to customers and users.

Many men who drive their own automobiles carefully, and boast about their great reliability and low maintenance, notwithstanding the small amount of attention they give them, do not always give due consideration to the great difference in the service of the street car and that of the average pleasure automobile. This difference would show up at once were they to start out some morning behind a street car and follow it all day long, making an average of a hundred and fifty miles with six to eight stops per mile, starting and stopping at the same rate as that of the street car.

The average electric railway executive, apparently, does not have a clear picture in his mind of the difference between the maintenance of several hundred or, perhaps, fifteen hundred to two thousand street cars and that of power plant or substation machinery, the latter consisting of what is termed "stationary machinery". This assumption appears warranted because of the greater interest and attention given to power plant machinery, as compared to rolling stock maintenance and inspection shops. This condition is especially peculiar, since the opportunity to waste a high percentage of the earnings in minor neglects and inefficient methods, resulting in dissatisfaction to patrons, is far greater in the rolling stock department than in any other department. In other words, on most railways, the maintenance of rolling stock department, by the very nature of the work, with its possibilities for high cost, failures in service, etc., is entitled to the best possible organization, with equal, if not better technical skill and talent than any of the other departments. But, unfortunately, this exists on only a few of the electric railways in this country.

Very little encouragement has been given to technically trained men to enter the maintenance department, and very little has been done toward developing technical skill among the regular inspectors. In the writer's opinion, this is a matter that is entitled to considerable thought on the part of railway managers and their immediate subordinates.

This same problem confronted our country during the war. It was discovered very early that the supply of skilled mechanics and technically trained men was wholly insufficient to meet the requirements and steps were taken immediately to develop and instruct the men. The best talent in the country was called to Washington to work out a system of three months' training for a very large number of picked men. The work was carried out, in all parts of the country, with marked success. In a similar way it would seem worth while for electric railways to establish a training school for a number of picked men and give them the opportunity to study and learn the technical side of the maintenance and inspection problem.

In discussing this subject with maintenance superintendents the writer has been told that it sounds all right, but that it is an uphill game, principally on account of the competition for skilled men that now prevails. About the time the training is finished, the man is attracted to another job that offers more pay. This was also assigned as the principal reason why the technically trained man does not enter the maintenance of equipment work. If he has vision and ambition, the goal ahead is, as a rule, that of master mechanic. He shortly finds that on most roads this position pays three or four thousand dollars per year and it would require ten to fifteen years to get there.

The job of master mechanic or superintendent of equipment should be lifted out of the rut it is in on a great many electric railways. The position in reality should be occupied by a man of talent and capacity equal to or higher than that of any other department. In the opinion of many, the very nature of the task calls for higher and better paid talent than other departments of electric railways. The position, furthermore, calls for a greater number of skilled and well-paid assistants than that of other departments, on account of the numerous and diversified branches of the mechanical and electrical art that it embraces.

All classes of work on maintenance of rolling stock call for some degree of mechanical or electrical talent, and present day rates for this grade of workmen are very high compared with a few years ago. Consequently, misapplied effort or careless work is far more costly than it has been heretofore. In other words, the investment in labor is high and, consequently, every hour of it must be properly supervised and directed.

The master mechanic who, heretofore, has taken great pride in the manufacturing end of his work must now give more time to inspection systems and methods, and study ways and means to prevent breakdown and failures, and to eliminate rapid mechanical wear, electrical burnouts, etc. That is his real maintenance job; manufacturing should be limited to only such parts as he finds too expensive to purchase.

The problem of holding skilled mechanics and attracting technically trained men is one that should be met the same as all other things that are governed by supply and demand. If satisfactory results are desired in anything where human skill is a factor, remuneration and other conditions must be made attractive.

The maintenance of rolling stock department should be the training ground for a large number of men required in other departments. Transportation department heads would be far better fitted for their positions if they had several years' training in the rolling stock department. In other words, technically trained men should be provided for the maintenance of equipment, maintenance of way and overhead line departments. Their opportunities for advancement should not be confined to their particular departments as they grow and develop. They should be given chances in other departments and thus open the door for promising young men to enter the industry and develop and grow with it.

M. B. LAMBERT

The Polar, Multi-Exposure, High-Speed Camera

J. W. Legg
Research Engineering Dept.,
Westinghouse Electric & Mfg. Company

THE development of photographic apparatus for scientific purposes has been rapid in the last few years. The stereoscopic effect of adjacent exposures in X-Ray work and in battlefield photographs was a material help in the war. Although probably more money is spent in the motion picture branch of photography than in all other branches combined, the ordinary motion picture has revealed but little to science that could not be observed by the unaided eye. To be sure, high speed motion picture cameras have been used for the study of moving objects and, in certain cases, for the study of arc phenomena. The most common form of motion picture camera takes pictures at the rate of about sixteen per second. Special cameras have been in use which take pictures of moving objects at several times this rate. However, to make a detailed study of electric arc phenomena, this rate of exposure must be increased not merely five times, nor thirty times, but one or two hundred times. This is especially necessary to obtain valuable data on the phenomena encountered in circuit breaker arcs and in commutator flashes.

The light in arc photography is so extremely intense that it is possible to use a small, inexpensive lens and still obtain a good arc picture when using a very short exposure. To prove this, the writer used a "Brownie" camera, stopped down to an aperture of f:40 and successfully obtained a picture of a circuit breaker arc when using an exposure of but seventy-five millionths of a second (0.000,075 sec.).

For high-speed work it is desirable to replace intermittent or reciprocating action by simple rotary motion. As is well known the cumbersome, slow speed, reciprocating engines, used to drive generators have been largely replaced by steam or water turbines. In the same way, a high speed, multi-exposure camera has been developed with the intermittent shutter movement of other cameras replaced by simple rotary motion. All parts of the camera remain stationary except the very light aluminum disc shutter. The lenses are quite inexpensive and are arranged staggered, in circles, with the shutter shaft as a center. The shutter consists of a thin aluminum disc, with a radial slot which exposes the lenses in sequence. The sides of the slot are cut along radii of the disc so as to give equal exposure to the lenses near and far from the center of rotation. By staggering the lenses more exposures can be obtained on the same plate and a greater number of exposures per second can be obtained with the same shutter speed.

A slot further from the center of the shutter, and diametrically opposite the main slot, uncovers lenses arranged in an outer circle so as to give simultaneous exposures for stereoscopic views. The stereoscopic lenses are spaced much further apart than the human eyes, so when the pictures are properly reversed and mounted in a stereoscope the object photographed appears nearer to the observer than it actually was from the camera.

There are twenty-two different lenses in the high speed camera shown in Fig. 1, giving sixteen successive exposures, on one 8 by 10 inch plate, six of the exposures have stereoscopic mates. This camera has been used to take pictures of arc phenomena at more than one-hundred times the rate normally used in mo-

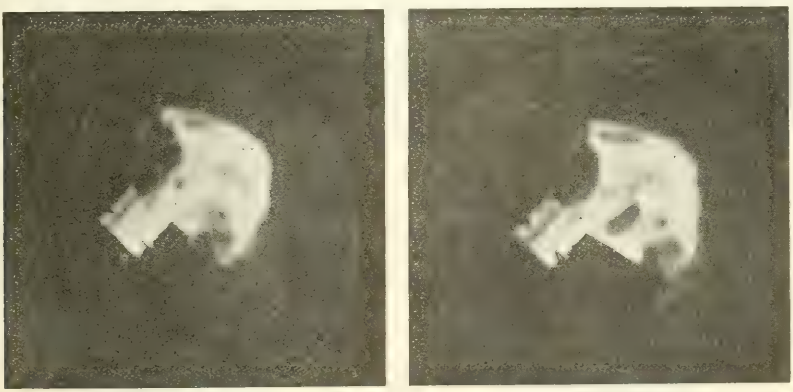

FIG. 1 ENLARGED STEREOSCOPIC PHOTOGRAPH OF AN ARC BEING MAGNETICALLY BLOWN OUTSIDE THE ARC CHUTES OF A STANDARD ELECTROPNEUMATIC RAILWAY SWITCH, AT 950 AMPERES AND 500 VOLTS

As the arc was traveling out at a speed as fast as that of a fast airplane, and as it was within a few feet of the lenses, it is readily seen that a really high-speed camera was required to take such a picture. The polar shutter was rotating at 5625 r.p.m., making exposures at the rate of 1500 per second, so that sixteen successive pictures were taken in 0.0107 sec.

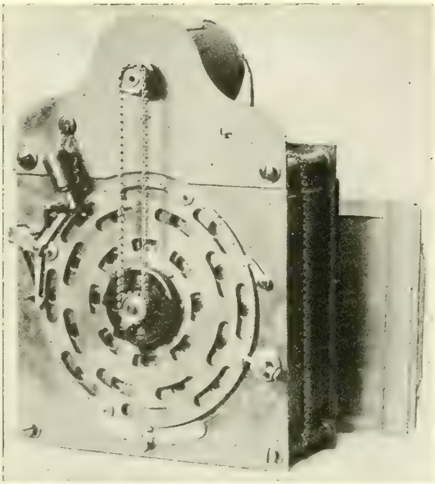

FIG. 2—FRONT VIEW OF THE POLAR, MULTI-EXPOSURE, HIGH-SPEED CAMERA

The driving motor at the top, through the transmission chain, drives the high speed shutter, which is mounted inside the camera just behind the lenses. Sixteen achromatic lenses are staggered in two circles about the shaft as a center and are exposed in sequence by the high-speed shutter. Six additional lenses are mounted in a third circle, diametrically opposite six of the lenses on the inner circle and are exposed simultaneously for stereoscopic pictures. The limiting shutter, which limits the exposure to one revolution of the high-speed shutter, is shown mounted in front of the lenses. This shutter is driven by a spiral spring mounted on the shaft bearing, the speed depending on the tightness to which this spring is wound. The trip magnet at the upper left corner releases the limiting shutter through an escapement, which permits one-eighth revolution for each action of the magnet. The limiting shutter is provided with an anti-bouncing device which prevents it from bouncing open after closing. It can also be held open permanently when the camera is used to take quick transient arcs. The camera is provided with a ground glass and is focused by right and left hand threads in the four corner posts, which are actuated by sprockets driven by a chain surrounding the case. An iris diaphragm plate is adjusted by the slide at the bottom of the limiting shutter to give apertures of f:16, f:32 and f:64 (most work being done at f:64). The camera back takes a regular 8 by 10 inch double plate holder.

tion picture work. At a shutter speed of ten thousand revolutions per minute this camera will take sixteen successive exposures (six of which have stereoscopic mates) in six thousandths of a second (0.006 sec.). This is at the rate of over twenty-six hundred exposures per second. The rate at which any set of

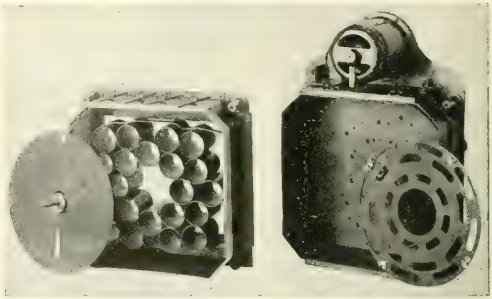

FIG. 3—PRINCIPAL PARTS OF THE HIGH-SPEED CAMERA DISASSEMBLED

At the left is shown the high-speed shutter with a radial slot for successive exposures and a circular slot for the stereoscopic mates. The baffles which prevent over-lapping of adjacent pictures are shown mounted in the front half of the camera. At the right is shown the interior of the front half of the camera with the high-speed shutter removed to show the iris diaphragm plate mounted just back of the lenses.

pictures is taken can be very accurately obtained by multiplying the number of revolutions per second, of the high speed polar shutter, by the number of successive lenses. With this camera a calibrated tachometer is used which indicates the revolutions per minute of the shutter. Thus at 7 500 r.p.m. of the shutter, the rate of exposure is: (7500/60) 16 = 2 000 exposures per second.

The particular arrangement of this polar shutter makes it possible to get clear cut exposures. As the width of the slot in the shutter is much less than the circular arc between adjacent lenses, and as the width of the slot is much greater than the diameter of the lens

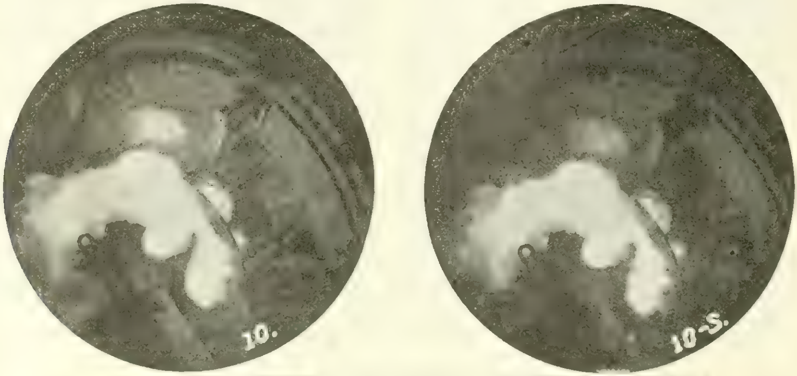

FIG. 4—EXPOSURES 10 AND 10S OF FIG. 5, MOUNTED STEREOSCOPICALLY

As these views are mounted with the original axis in line, the bearing pedestal appears somewhat tilted. Much of the fine detail in the original photograph is lost in the reproduction, but the mates serve to give an idea of the "life" that appears in the stereoscopic view. Figs. 3 and 5 are printed back to back so that they may be cut out together for viewing in a stereoscope. They can be seen stereoscopically without a stereoscope, by interchanging the pictures (right and left) and converging the lines of vision of the eyes, (looking crosseyed) at a point about half way to the pictures, and focussing the eyes on the pictures to get sharp vision.

iris, the actual time from the very beginning of one exposure to the very end of that exposure is much less than the time from one exposure to the next.

The focusing of the twenty-two lenses (which, with the small aperture used, are sufficiently well matched) is accomplished by a right and left hand screw motion into four sets of posts, near the horizontal edges of the camera case. The screws are actuated simultaneously, by four sprockets meshing with a single, encircling chain.

Another disc is fitted with several diaphragms for each lens. This enables them to be stopped down to the desired aperture, simultaneously. The controlling knob, and its light tight joint, can be seen near the lower edge of the front face.

The operation is very simple for transient arc phenomena, such as the magnetic blowout of the electric arc established by the opening of a switch or circuit-breaker. It is only necessary to drive the high speed, polar shutter at such a speed that it will make one revolution in but slightly greater time than it takes for the arc to be extinguished. A universal type driving motor is used, suitable for operation on either direct or alternating current. Where direct current is available it is connected as a shunt motor with its armature across a potentiometer, so as to give a great range of shutter speed. Should the speed of the shutter be too great, an overlapping of pictures would ensue; and, on the other hand, too slow a shutter speed would simply fail to give the full number of pictures.

This procedure is also applicable to flash-overs on generators and rotary converters, when the flash lasts for but a short period of time. The simplicity of operation is apparent from the fact that every picture of transient phenomena has come out successfully.

For recurrent arcing, such as in arc welding; or for persistent flashing on commutators, etc., it becomes necessary to use an extra shutter which will limit the exposure to one revolution of the high speed shutter. It is impracticable to start the high speed shutter from rest and have it pass its slot by the set of lenses and then come to a stand-still, all in the short space of time

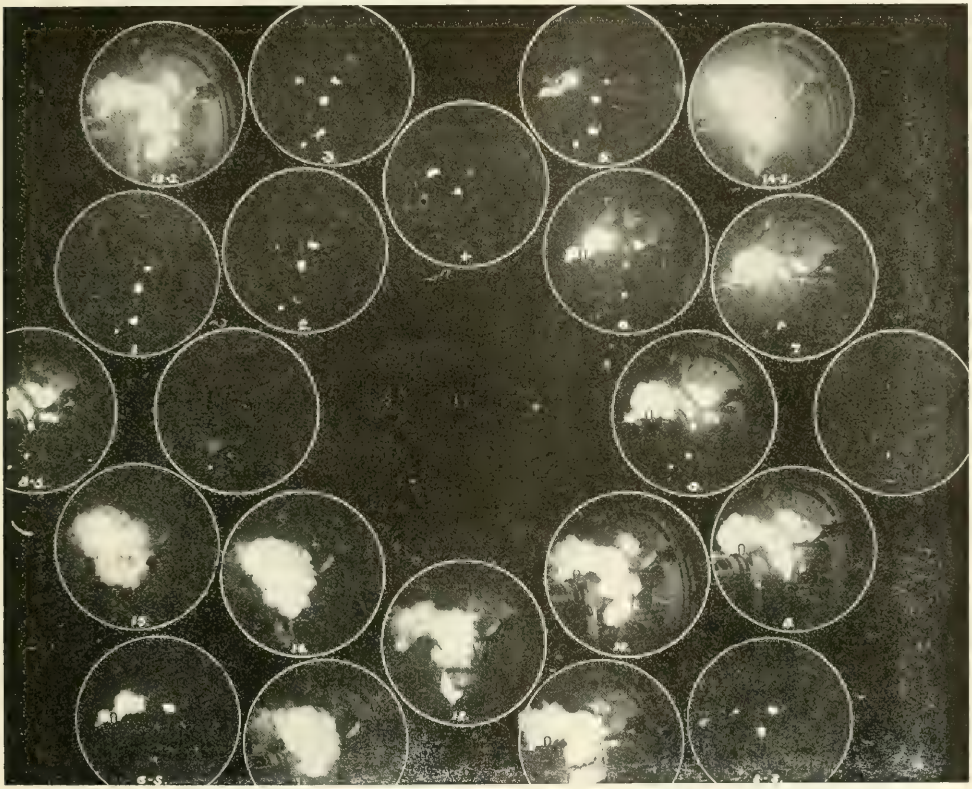

FIG. 5—MODERATE SPEED, POLAR PHOTOGRAPH OF A FLASH ON THE COMMUTATOR OF A ROTARY CONVERTER

These pictures (taken at the rate of 560 exposures per second) show only the first quarter of the flashing, as the exposure was cut short by the limiting shutter after one revolution of the high-speed shutter. Although this is only a moderate speed photograph, in the original print exposures 8, 9 and 10 show clearly the hexagonal nuts on the rapidly revolving commutator. These individual pictures are sufficiently sharp to stand enlarging to four or five diameters without loss of detail. The building up of the arc is clearly shown in the successive pictures.

required. While the high-speed shutter (located within the camera case) is making one revolution at a strictly uniform speed, the limiting shutter passes its slots by the twenty-two lenses at an accelerated speed and comes to a stand-still after traveling only one-eighth of a revolution. This limiting shutter is driven by a spiral spring which may be wound up more or less according to the total length of exposure desired.

If it be desired to take pictures showing the start of a flash over on a rotary converter, for example, it is only necessary to have the high-speed shutter revolving at a rate which will make one revolution between the time the overload is thrown on the converter and the time the limiting shutter closes the whole set of lenses. The limiting shutter is electro-magnetically tripped at the same time the switch throws on the overload or short-circuit. When using the limiting shutter for the first time, it was necessary to take but one trial exposure before good results were obtained.

Before baffles were provided some of the exposures were impaired by stray light from an adjacent lens. These baffles consist of twenty-two tubes placed in the camera box between the lenses and the plate. These tubes could not extend all the way to the plate, for when arcs are photographed near the camera the center distances between pictures, are greater than when photographing a distant arc.

Each of the twenty-two pictures is about one and three-quarters inches in diameter. By adding enlarging spectacle lenses to a standard stereoscope the small pictures appear as large as standard stereoscopic views. For use in such a stereoscope, the mates should be cut out from the 8 by 10 inch print and interchanged (left for right, and right for left) and mounted with their original common center line still in line.

The stereoscopic effect increases the value of arc photographs greatly, as it shows plainly the third dimension. In some cases, for instance, a single picture seemed to show a somewhat flattened crescent arc, while the stereoscopic views showed two crescent arcs in different planes. The stereoscopic view shows very plainly when the arc bends towards or away from the camera. Another case of the value of the stereoscopic view was demonstrated in a picture of a flash-over on a rotary converter when the single exposure seemed to indicate that an arc struck to the end frame, while the stereoscopic view showed that the arc actually was several feet beyond the end frame and was coming from a brushholder supporting bolt.

To the engineer in charge of the apparatus being photographed some of the most valuable pictures are the least spectacular. Also some of the most spectacular pictures are of the least value to the engineer. The value of most pictures is increased when an oscillograph record, of current and voltage, is made simultaneously. By a convenient arrangement the pressure of a single button operates the mechanism being studied, the oscillograph, and the high-speed camera, so as to give simultaneous records. For safety in extreme cases, this button can be located outside of the building in which a dangerous test is being made.

Automatic Push Button Elevators

H. L. Keith

PUSH button control is used where operation is rather infrequent, so that it is practical to dispense with the services of an operator. This is very desirable in many instances, and the saving in operators' wages will soon more than make up the difference in the first cost. Elevators in hospitals, clubs, apartment houses and private residences are typical examples. Where traffic is heavy and continuous, as in offices and stores, push button control should not be attempted, since efficient service and proper schedule cannot then be maintained without an attendant.

This equipment is arranged with a push button at each floor or landing to be pressed by the passenger to call the car, as is customary in any elevator installation. If the car is not in use, it will promptly respond to the call. When the car arrives at the landing, the waiting passenger immediately opens the door, enters the car and closes the door. Inside the car is a push button box containing as many buttons as there are floors, with each button marked to correspond. When the proper button is pressed, the car moves to the desired floor and stops without attention from the passenger. The door should be immediately opened, and after the passenger leaves the car the door should be closed again, unless it is of the self-closing type. The controller for such elevators is simple and substantial in construction and very reliable.

The elevator motor, control panel and drum hoisting machine are essentially the same as used with elevators requiring an operator, except that the master controller or car switch is replaced by a gang button box, and the geared limit switch on the winding drum is replaced by a floor stop device or selector, geared to the drum shaft. The control panel consists of a slate base on which are mounted the necessary magnetic contactors for reversing the motor, energizing the brake and field magnets and accelerating the elevator smoothly and safely.

The floor stop device, Fig. 3, consists of a substantial iron wheel with a copper rim or tire. The wheel is revolved on a steel shaft supported by an iron mounting bracket. The mounting bracket also supports a number of relays or magnetic contactors, one for each floor, each relay coil connecting with the operating push buttons in the car and at the various floors. An emergency stop magnet is arranged so that it nor-

mally holds the floor relays mechanically inoperative. This magnet is controlled by the stop button in the car, by the hatchway limit and slack cable switches and by a mechanically operated cam on the floor stop wheel,

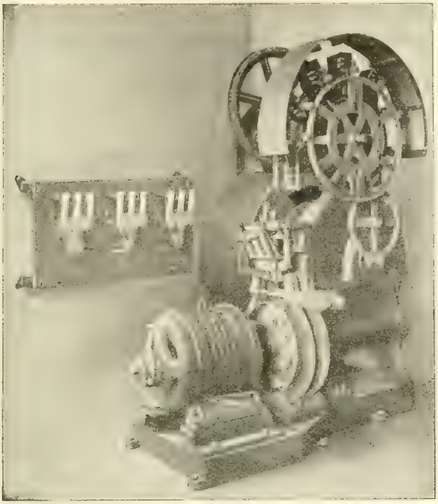

FIG. 1 ALTERNATING-CURRENT EQUIPMENT FOR AUTOMATIC ELEVATOR

which revolves simultaneously with the movement of the elevator car.

The operation of such a system is quite simple. When a button is pushed, it energizes a floor relay and the emergency magnet on the floor stop device. The relay makes contact on the rim of the wheel for the line contactor and the proper direction

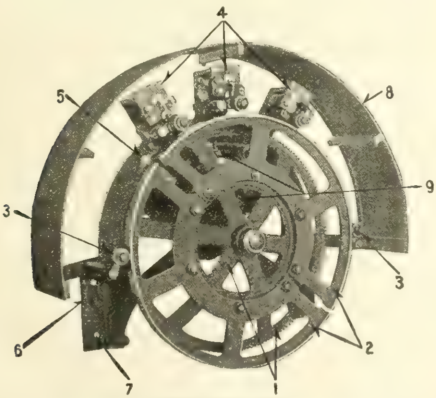

FIG. 3—FLOOR STOP DEVICE

1—Gear. *2*—Contact Wheel. *3*—Contacts, one for each direction. *4*—Floor relays to complete the circuit to the controller. One relay is required for each floor. *5*—Cam which resets relay to stop the elevator. *6*—Mounting frame. *8*—Protecting cover with cleats to support the wiring. *9*—Emergency stop magnet.

contactor on the control board. The closing of these contactors prevents the operation of any other floor relays. The car then proceeds toward the desired landing. Should it happen that two or more buttons were operated at the same instant, the car would respond to the call of one and the emergency magnet would automatically reset all other floor relays. The cam on the

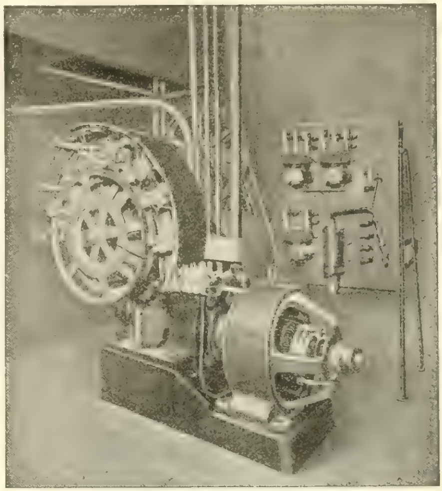

FIG. 2—DIRECT-CURRENT EQUIPMENT INSTALLED UPON AUTOMATIC ELEVATOR

floor stop, 5 Fig. 3, resets the floor relay, opening the control circuit to the main and reversing contactors at the proper time, as the car approaches the floor. The emergency magnet is de-energized by the opening of the reversing contactors. This magnet may be de-energized at any time by pushing the stop button in the

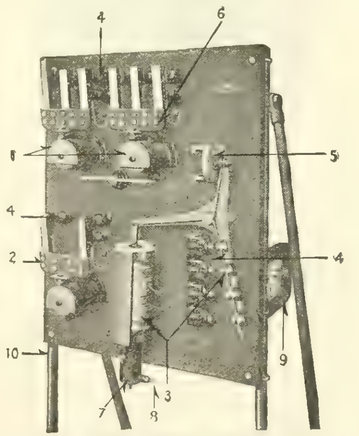

FIG. 4—DIRECT-CURRENT CONTROL PANEL

1—Mechanically interlocked directional contactors. *2*—Line contactor. *3*—Accelerating contactor. *4*—Contacts are interchangeable. *5*—A non-interference device to prevent the car from being "stolen". *6*—A flexible shunt relieves all bearings from carrying current. *7*—Time element dashpot. *8*—Adjustment for time of acceleration is easily made. *9*—Starting resistor.

car, thereby re-setting any floor relay. The floor relays are reset mechanically when the emergency magnet is de-energized and they can be operated again to

start the car only upon proper release of the emergency magnet. The passenger therefore has complete control over the movement of the car through the push button station.

In setting up the floor stop device, the position of the cam must correspond to that of the elevator car with respect to any landing and the floor relays *4* are moved along their mounting bracket to correspond with the distances between the various landings. The top and bottom relays should be as far apart as practical and the intermediate relays to suit. To accomplish this a pinion having a suitable number of teeth must be chosen. The wheel has teeth in the entire periphery so that the pinion may be located as most convenient. If the gear ratio is such that the movement of the cam is very slow, it will be necessary to have the cam brought to a fairly sharp point, so that the car will stop correctly, up or down. The speed of the car and the speed with which the brake sets in stopping the car will determine how broad the cam must be. The

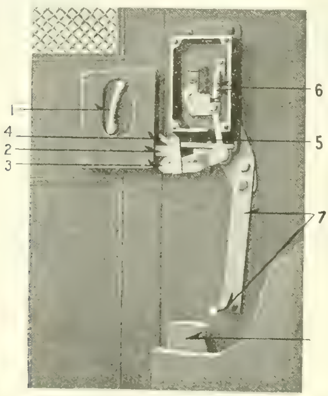

FIG. 5—COMBINATION DOOR LOCK AND SWITCH

1—Handle for opening door. *2*—Latch on door. *3*—Catch. *4*—Safety lock. *5*—Stop pin for safety lock. *6*—Contacts, closed only when door is locked. *7*—Lever which permits lifting of safety lock when car cam is in position to prevent it from swinging toward the car. This lever does not engage with the cam except in the act of unlatching the door. *8*—Cam on car. When car is at a floor, the cam is in position to allow the door to be opened.

farther apart the relays can be set, the more accurately the stops will be accomplished. The cam is made in two pieces, slotted so that they can be moved independently (one for *up* and one for *down*).

A non-interference interlock is arranged to open the circuit to the floor relays after any button is pushed, making it impossible for anyone to interfere with a car which has responded to a call or contains passengers. The non-interference interlock is controlled by a dashpot which has a definite time limit (adjustable), usually set for about five seconds, so that after the car is stopped at any floor it cannot immediately be started again, thereby allowing pasengers sufficient time to open the door, but not permitting the passengers to hold the car for an unreasonable period, unless the door is held open or the stop button held pressed. If a waiting passenger pushes a floor-button while the car is in use, it is necessary for him to push it again after the car is left unoccupied.

The construction of the push buttons is worthy of note. A substantial graphite disc with a hole through the center rides on a steel shaft, the button and compression spring also riding on the shaft. The stationary contacts are two graphite buttons mounted on an insulating base. The whole is enclosed in a metal case with an ornamental cover. The removal of two screws from the cover releases the parts for inspection. Each button in the car is a unit with a separate removable cover. Graphite contacts require no cleaning or attention until worn out, and will carry the control circuit current with lighter contact pressure than is the case with metal contacts, which soon become corroded and dirty. Therefore no undue effort is required to operate the buttons.

One of the most important features of automatic elevator control is embodied in the door contacts, which prevent the operation of the elevator while any door is open. If these contacts were independent of the lock or latch, the door might close without latching closing the switch and allowing the car to be started, after which the door might open, due to vibration or accident, and the car be stalled between floors. This has often been a great source of trouble and annoyance. Fig. 5 illustrates a door contact which is combined with the door locking mechanism. The butt-contact members *6* are of graphite, identical with the stationary push button contacts. One of these is attached to the moving element and the shock of closing the contacts is absorbed in a compression spring. Proper pressure is maintained between contacts without injury, no matter how hard the door is slammed; in fact the motion of the door is not transmitted to the contact members. They are closed independently by the latch and safety lock, *2* and *4*. The contacts carry the control circuit from the push buttons. No current is broken and there is no burning or arcing at the contacts when the door is opened. The combination door lock and switch is so arranged that the switch contacts are open and the elevator is inoperative unless the door is latched. Not until the door latch has fallen into place, thereby closing the door switch, can the elevator be started. Closing the door fully, without latching it, will not close the switch; however, the door will automatically latch when closed unless there is some obstruction. No door can be opened unless the car is at that floor. A cam or shoe of the car engages with lever *7* when the handle *1* is operated to open the door. The lever *7* is moved against the cam in opening the door, but at other times does not touch the cam, so that there is no striking as the car passes the floors, unless the handle is pulled over as the car is passing the floor. In some cases it is advisable to provide a magnet-operated cam so that the cam is held away from contact with the lever *7* unless the car is at the landing.

Electrical Characteristics of Transmission Circuits-V

Wm. Nesbit

SPEED OF ELECTRIC PROPAGATION

ASTRONOMERS and investigators by various methods of determination have arrived at slightly different values for the speed of light. The Smithsonian Physical Tables give 186 347 miles per second as a close average estimate. In electrical engineering, the speed of light is usually stated as approximately 3×10^{10} centimeters per second. This is the equivalent of 186 451 miles per second. The speed of electrical propogation (assuming zero losses) is the same as that of light.

ELECTRIC WAVE LENGTH

Suppose a frequency of 60 cycles per second is impressed upon a circuit of infinite length. At the end of one sixtieth of a second the first impulse (neglecting retardation due to losses) will have traversed a distance of 186 347 ÷ 60 or 3106 miles. A section of such a circuit 3106 miles long would be designated as having a full wave length for a frequency of 60 cycles per second.

In Fig. 14, the dotted line or one cycle wave is shown as extending over a circuit 3106 miles long. In this case, when the first part of the wave arrives at a point 3106 miles distant, the end of the same wave is at the beginning of the circuit. For each half wave length the current is of equal value but flowing in opposite directions in the conductor. Such a circuit is designated as of full wave length. Since the velocity of the electric propagation is slightly less than that of light, being slightly retarded due to resistance and leakage losses, the actual wave length will be slightly less than 3106 miles. Thus for a 300 mile, 60 cycle, three-phase circuit consisting of No. 000 copper conductors having 10 ft. flat spacing, the wave length is calculated to be 2959 miles. The wave length of such a circuit is indicated by the heavy line on the accompanying sketch. In the case of this particular circuit the electric field has been retarded approximately five percent, due to the losses of the circuit, as indicated by the displacement of the dotted and full line curves.

QUARTER WAVE RESONANCE

If the end of a long trough filled with water is struck by a hammer, the impact will cause a wave in the water to start in front of the point of impact and travel to the far end of the tank. When this wave reaches the far end of the tank it will be reflected, traveling back toward the point of origin, but on account of resistance encountered it will be of diminishing height or amplitude. If, at the instant it gets back to the point of origin, the end of the tank is again struck by the hammer, the resulting impulse will be that due to the second hammer blow plus that remaining from the first blow. The result will be that the second wave from the near end of the tank will be of greater amplitude than the first wave. If when the second wave arrives back at the near end, the end of the tank is struck again with the hammer the resulting third impulse will be of greater amplitude than the second impulse. If at the instant of the return of each succeeding impulse the end of the tank is struck, the result will be cumulative and each succeeding wave will be of greater magnitude than the one preceeding until the point is reached where the losses due to resistance become sufficient to prevent a further increase in amplitude of the wave.

Under certain conditions a similar phenomen many occur in electric circuits and this is known as "quarter wave resonance". If an electric impulse* is sent into a

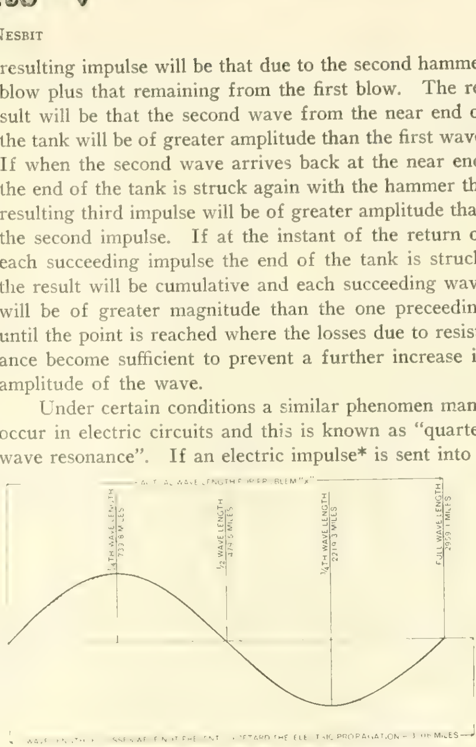

FIG. 14—WAVE LENGTH OF 60 CYCLE CIRCUIT

conductor, such as a transmission circuit, this impulse travels along the conductor at the velocity of light. If the circuit is open at the other end, the impulse is there reflected and returns at the same velocity. If at the moment when the impulse arrives at the starting point a second impulse is sent into the circuit, the returned first impulse adds itself to, and so increases the second impulse; the return of this second impulse adds itself to the third impulse, and so on; that is, if alternating impulses succeed each other at intervals equal to the time required by an impulse to travel over the circuit and back, the effects of successive impulses add themselves, and large currents and high e.m.f.'s may be produced by small impulses. This condition is known as quarter wave electric resonance. To produce this condition, it is necessary that the alternating impulses occur at time intervals equal to the time required for the impulses to travel the length of the line and back. For example, the time of one half wave or cycle of impressed e.m.f.

*For a complete study of this subject see "Transient Electric Phenomena and Oscillations" by C. P. Steinmetz, from which the above description of quarter wave resonance has largely been taken.

is the time required by light to travel twice the length of the line, or the time of one complete cycle is the time light requires to travel four times the length of the line. Stated another way, the number of cycles or frequency of the impressed alternating e.m.f.'s in resonance condition, is the velocity of light divided by four times the length of the line; or to have free oscillation or resonance condition, the length of the line is one quarter wave length of light. The cycles at which this condition is reached (if there were no losses present) would be determined as follows:—

$$\textit{Frequency} = \frac{46587}{\textit{Length in miles}} \quad \text{(23)}$$

or

$$\textit{Length in miles} = \frac{46587}{\textit{Frequency}} \quad \text{(24)}$$

RESONANCE LENGTHS OF CIRCUITS

Commercial frequencies are so low that to reach a quarter wave resonance condition with them the circuit would have to be of great length. The following values, for the sake of simplicity, are based upon the assumption that there are no losses in the circuit.

Fundamental Frequency	Resonance Length	Wave Length
15 cycles	3106 miles	12 434 miles
25 cycles	1863 miles	7452 miles
40 cycles	1165 miles	4660 miles
60 cycles	776 miles	3106 miles

The above lengths are based upon the impressed or fundamental frequencies. If these impressed frequencies contain appreciable higher harmonics, some of the latter may approach resonance frequency and, if of sufficient magnitude, may cause trouble. Thus the length of circuit corresponding to resonance conditions of various harmonics of the fundamental is given below.

Cycles	Harmonics		
	3rd.	5th.	7th.
15	1035 miles	631 miles	444 miles
25	621 miles	372 miles	266 miles
40	388 miles	233 miles	166 miles
60	258 miles	155 miles	111 miles

Thus an impressed frequency of 60 cycles will not produce quarter wave electric resonance unless the circuit be approximately 776 miles long. If a third harmonic, however, is present in the impressed wave, this harmonic will develop quarter wave resonance in a circuit approximately 258 miles long, a 5th harmonic in a circuit approximately 155 miles long, and a 7th harmonic in a circuit approximately 111 miles long.

The above values are based upon no losses being encountered in transmission. Obviously this is an incorrect assumption, as electric propagation is always accompanied by more or less loss, depending upon the fundamental constants (resistance and leakage) of the circuit. The effect of such losses is to retard the velocity of the electric propagation, usually by an amount of five to ten percent below that of light. The above values of circuit lengths representing a condition for resonance may therefore be as much as ten percent above the actual lengths.

An investigation of the effects of higher harmonics of the impressed wave is of importance in connection with very long distance transmission systems.

PARALLELING TRANSMISSION CIRCUITS

Transmission lines are frequently constructed with duplicate circuits which are normally operated in parallel. In other cases two circuits may lead from the generating station in divergent directions and at some distant point come together and be connected in parallel.

If the two circuits are fed from different generators, or sources of supply, the only condition necessary for paralleling the circuits is that the phase rotation of the two circuits be the same and that the regulation in speed of the prime movers of the generators feeding the two systems can be adjusted so as to bring the phases of the two circuits together for paralleling.

If, however, the two circuits which are to be connected in parallel are fed from the same source of supply, the case may become involved. There will be no trouble in obtaining the correct phase rotation, for should the circuits not rotate alike, it is only necessary to transpose any two of the connections of either of the circuits (assuming that the circuits are three-phase). The other condition to be met is that the phases of both circuits to be paralleled are the same, i. e., the voltages in the phases to be paralleled must pass through their zero and maximum values at the same instant.

If neither circuit has transformers between the points where they are to be connected in parallel, their phases will coincide and there will be no trouble about connecting them in parallel. If one circuit has no transformers and the other has transformers, the phase relations of the two circuits will depend upon the kind of transformer connections employed. Suppose it is assumed that the raising transformers are connected delta to star and the lowering transformers are connected delta to delta. With these connections the phases of the two circuits will be 30 electrical degrees apart and it will be impossible to parallel the circuits. In other words one delta-star or star-delta transformer connection produces a phase displacement of 30 degrees. It will be obvious that a second delta-star or star-delta connection will restore the original phase relation. A delta-delta connection or a star-star connection does not affect the phase relations. If both circuits have an even number of star and even number of delta windings, the equivalent resultant will be the same as if all the connections were either delta-delta or star-star; hence, there will be no resultant change in phase relations and the two circuits can be paralleled with each other or with a circuit having no transformations. If, however, both circuits have an odd number of delta and an odd number of star windings, any attempt to resolve them into the equivalent number of delta-delta and star-star connections will leave one star and one delta; the effect is the same as if there was one star-delta connection in the circuits. This will twist the phase relations of the terminals 30 degrees out of phase from the generators. Since both circuits will have an

equivalent phase displacement, they can be paralleled with one another, but since both are 30 degrees out of phase with the generators, they cannot be paralleled with a line having no transformations; nor with a line having an even number of star and delta connections.

When the phase angles of the two transmission circuits (receiving their power from a common source) are known to be such as to permit of parallel operation it is then necessary to phase them out before connecting the circuits together. The phase rotation can be checked most readily by means of a polyphase motor connected first to one circuit and then to the other, being careful to connect the leads in the same order in each case. If the motor runs in the same direction from both circuits, the phase rotation of the circuits will be the same. The phase angle can be readily tested by means of a single-phase synchroscope*. In case a polyphase motor and synchroscope are not available, the phasing out of the circuits may be accomplished by the use of a voltmeter and transformer.** As an illustration, assume that from a 4400 volt bus in a generating station a 4400 volt transmission circuit extends for some distance from the station. A second transmission circuit fed from the same bus but containing both raising and lowering transformers is to be paralleled at the farther end with the 4400 volt circuit which contains no transformers. The phase angles of the lines are assumed to be such as to permit paralleling the two circuits, with proper connections.

One of the transmission circuits is connected to one side of the paralleling switch as in Fig. 15 and the other circuit to the other side of the same switch. The three terminals on one side of the switch may be tagged *1-2-3*. Likewise the three terminals on the other side of the switch may be tagged *4-5-6*. Connect any two terminals together (*1* and *4* in this case) by a jumper. Take voltage readings across the corresponding terminals *2* to *5*, *3* to *6*, and *3* to *5*, *2* to *6*. From these voltage readings it is a simple matter to indicate by a vector diagram the relative phase relations at the switch contacts of the two circuits to be paralleled. In the case illustrated, the readings indicate that the relative voltage relations on the two sides of the paralleling switches are as indicated by the full line delta *1-2-3*, and the broken line delta *4-5-6*. It will be seen that phase *1-3* will parallel with phase *4-5*, that phase *1-2* will parallel with phase *6-5* and phase *2-3* will parallel with phase *4-6*. In order to bring about this phase relation it will be necessary to change the transformer connections on the low-tension side of the lowering transformers, inside of the delta. That is the *6* end of the transformer windings *5-6* will be connected to the *4* end of transformer *4-5*. The *4* end of transformer *4-6* will be connected to the *5* end of transformer, *5-6* and the *6* end of transformer *4-6* will be connected to the *5* end of transformer *4-5*. These changes will shift the position of the delta *4-5-6* so that it will coincide with delta *1-2-3*. A further test of voltage between switch terminals *2* to *5* and *3* to *6* should indicate zero voltage across the switch terminals to be connected together, in which case the paralleling switches may be closed. In order to measure the voltage across the paralleling switch contacts it will usually be necessary to employ a potential transformer. This transformer and voltmeter should be capable of withstanding 1.73 times the voltage of the circuit for, with the connections given in Fig. 15, one reading gave 7610 volts, whereas the voltage of the circuit was only 4400 volts.

In case there is a ground on both systems, the placing of a jumper across two of the switch contacts would result in a short-circuit. This jumper should not be placed across the switch until it has been shown by connecting a transformer across these two contacts that no potential exists between them.

*These tests are described in an article on "Phasing Out High Tension Lines" by E. C. Stone in the JOURNAL for Nov. 1917, p. 448.

**This method is described in an article on "Determination of Polarity of Transformers for Parallel Operation" by W. M. McConahey, in the JOURNAL for July 1912, p. 613. See also article on "Polarity of Transformers" by W. M. Dann in the JOURNAL for July 1916, p. 350.

HEATING OF BARE CONDUCTORS IN AIR

If the circuit is long, the voltage will probably be high and consequently the current to be transmitted small. In this case, the heating effect of the current will be small and unimportant. If, however, the circuit is short and an unusually large amount of power is to be transmitted, the current will be large. Since the I^2R loss varies as the square of the current and directly as the resistance, the heat generated, if the current is large, may be sufficient to overheat or anneal the material of the conductors. In some cases of unusually large amounts of power being transmitted short distances, the heating effect of the currents resulting may be sufficient to limit the amount of power that can be transmitted at a given voltage.

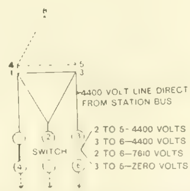

FIG. 15—TEST FOR PHASE SEQUENCE

Table XXIII should be consulted in cases where the circuit is short and the amount of power to be transmitted large. In this table are columns containing current values which have been calculated corresponding to 10, 25 and 40 degrees C. rise in temperature for various sizes of bare copper conductors suspended in still air at a temperature of 25 degrees C. In other words these current values are based upon absolute temperatures of 35, 50 and 65 degrees C. The current values corresponding to a temperature rise of 40 degrees C.

TABLE XXIII—HEATING CAPACITY FOR 40° C. RISE

OF BARE COPPER CONDUCTORS SUSPENDED OUT OF DOORS

CONDUCTORS				AMPERES – BARE CONDUCTORS IN STILL AIR FOR TEMPERATURE RISES STATED			APPROXIMATE CARRYING CAPACITY IN K.V.A. 3 PHASE CORRESPONDING TO A TEMPERATURE RISE OF 40° C (BASED UPON AMPERES IN COLUMN MARKED "FOR 40°C RISE") FOR BARE COPPER CONDUCTORS SUSPENDED IN STILL AIR OUT OF DOORS.									
TYPE	B & S NO.	AREA IN CIRCULAR MILS	DIAMETER IN INCHES	FOR 10°C RISE	FOR 25°C RISE	FOR 40°C RISE	220 VOLTS K.V.A.	440 VOLTS K.V.A.	550 VOLTS K.V.A.	1100 VOLTS K.V.A.	2200 VOLTS K.V.A.	4000 VOLTS K.V.A.	4400 VOLTS K.V.A.	6000 VOLTS K.V.A.	6600 VOLTS K.V.A.	6900 VOLTS K.V.A.
STRANDED		2 000 000	1.631	2140	3280	4050	1540	3080	3850	7700	15 400	27 900	30 800	42 000	46 200	48 300
		1 800 000	1.548	1980	3020	3760	1430	2860	3580	7150	14 300	26 000	28 600	39 100	42 800	44 800
		1 700 000	1.504	1890	2920	3600	1370	2740	3420	6850	13 700	24 800	27 400	37 400	40 000	43 000
		1 600 000	1.459	1810	2780	3440	1310	2620	3270	6550	13 100	23 800	26 200	35 800	39 200	41 000
		1 500 000	1.412	1720	2640	3300	1250	2500	3140	6280	12 560	22 800	25 [illegible]20	34 300	[illegible]	39 200
		1 400 000	1.364	1635	2520	3100	1180	2360	2950	5900	11 800	21 400	23 600	32 200	35 400	37 000
		1 200 000	1.263	1460	2230	2760	1050	2100	2620	5250	10 500	19 100	21 000	28 700	31 500	33 000
		1 100 000	1.209	1360	2100	2580	980	1960	2460	4920	9840	17 800	19 680	26 800	29 400	30 800
		1 000 000	1.152	1270	1950	2420	920	1840	2300	4600	9200	16 700	18 400	[illegible]	[illegible]	28 800
		950 000	1.123	1215	1870	2320	880	1760	2200	4400	8800	16 000	17 600	24 100	[illegible]	[illegible]
		900 000	1.093	1175	1800	2220	840	1680	2110	4220	8440	15 300	16 880	23 000	25 300	[illegible]
		850 000	1.062	1120	1720	2130	810	1620	2030	4050	8100	14 700	16 200	22 100	24 300	25 400
		800 000	1.031	1075	1640	2030	770	1540	1930	3870	7740	14 000	15 480	[illegible]	23 200	24 200
		750 000	.998	1025	1580	1940	740	1480	1840	3690	7380	13 400	14 760	20 200	[illegible]	23 200
		700 000	.964	980	1490	1830	695	1390	1740	3480	6960	12 600	[illegible]	[illegible]	[illegible]	[illegible]
		650 000	.929	920	1410	1740	660	1320	1660	3320	6640	12 000	13 280	[illegible]	[illegible]	20 800
		600 000	.893	870	1330	1630	625	1250	1560	[illegible]	6240	11 300	12 480	[illegible]	18 700	19 600
		550 000	.855	810	1250	1530	580	1160	1450	[illegible]	5800	10 600	[illegible]	15 400	[illegible]	18 300
		500 000	.815	755	1160	1430	545	1090	1360	2720	5440	9860	10 880	14 900	16 300	17 100
		450 000	.772	700	1060	1320	500	1000	1250	[illegible]	5000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		400 000	.728	640	980	1210	460	920	1150	[illegible]	4600	8350	[illegible]	12 600	13 800	[illegible]
		350 000	.681	575	885	1040	415	830	1040	2080	4160	[illegible]	8320	[illegible]	2400	[illegible]
		300 000	.630	515	785	970	370	740	920	[illegible]	3680	[illegible]	7360	10 100	[illegible]	[illegible]
		250 000	.575	450	685	840	320	640	800	1600	3200	5800	6400	[illegible]	9550	[illegible]
	0000	211 600	.528	385	605	750	285	570	715	1430	2860	5170	5720	[illegible]	[illegible]	[illegible]
	000	167 772	.470	330	508	625	238	475	595	[illegible]	2380	4320	4760	[illegible]	[illegible]	[illegible]
	00	133 079	.418	280	425	527	200	400	500	[illegible]	[illegible]	[illegible]	4000	5470	[illegible]	6280
	0	105 560	.373	235	360	444	170	336	423	846	1692	3060	3384	4600	[illegible]	[illegible]
	1	83 694	.332	195	300	370	141	282	352	[illegible]	1408	2550	[illegible]	3840	[illegible]	4400
	2	66 358	.292	162	250	307	116	233	292	[illegible]	[illegible]	2120	2336	[illegible]	[illegible]	[illegible]
	3	52 624	.260	136	210	258	98	196	245	490	980	1770	1960	2680	2940	[illegible]
	4	41 738	.232	114	176	235	89	178	224	448	896	1620	1792	2440	[illegible]	[illegible]
	5	33 088	.206	96	147	182	69	138	173	346	692	1260	1384	1890	2080	[illegible]
SOLID	0000	211 600	.460	370	565	728	275	550	690	1380	2760	5030	5520	7550	8300	[illegible]
	000	167 772	.410	310	475	588	224	448	560	1120	2240	4060	4480	6100	6700	[illegible]
	00	133 079	.365	258	420	495	188	376	470	940	1880	3420	3760	5150	[illegible]	[illegible]
	0	105 560	.325	218	335	415	158	316	395	790	1580	2860	3160	4300	4730	4950
	1	83 694	.289	182	280	348	132	264	330	660	1320	2400	2640	3620	3970	4150
	2	66 358	.258	154	235	295	112	224	280	560	1120	2040	2240	3060	3370	[illegible]
	3	52 624	.229	128	200	245	93	186	233	[illegible]	930	1690	1860	2540	[illegible]	[illegible]
	4	41 738	.204	108	167	207	78	158	197	394	788	1430	1576	2150	2360	[illegible]
	5	33 088	.182	90	140	174	66	132	165	330	660	1200	1320	1810	1980	[illegible]

TYPE	B & S NO.	AREA IN CIRCULAR MILS	DIAMETER IN INCHES	FOR 10°C RISE	FOR 25°C RISE	FOR 40°C RISE	10 000 VOLTS K.V.A.	11 000 VOLTS K.V.A.	13200 VOLTS K.V.A.	15000 VOLTS K.V.A.	20000 VOLTS K.V.A.	22000 VOLTS K.V.A.	30 000 VOLTS K.V.A.	33 000 VOLTS K.V.A.	50 000 VOLTS K.V.A.	60 000 VOLTS K.V.A.
STRANDED		2 000 000	1.631	2140	3280	4050	70 000	77 000	92 200							
		1 800 000	1.548	1980	3020	3760	65 000	71 500	85 500	97 500						
		1 700 000	1.504	1890	2920	3600	62 300	68 500	82 000	93 500						
		1 600 000	1.459	1810	2780	3440	59 500	65 500	78 500	89 200						
		1 500 000	1.412	1720	2640	3300	57 000	63 000	75 300	85 500						
		1 400 000	1.364	1635	2520	3100	53 600	59 000	70 600	80 500						
		1 200 000	1.263	1460	2230	2760	47 700	52 500	63 000	71 600	[illegible]					
		1 100 000	1.209	1360	2100	2580	44 600	49 000	58 700	67 000	89 200	98 000				
		1 000 000	1.152	1270	1950	2420	41 800	46 000	55 200	63 000	83 600	92 000				
		950 000	1.123	1215	1870	2320	40 000	44 200	53 000	60 200	80 000	88 400				
		900 000	1.093	1175	1800	2220	38 400	42 200	50 500	57 500	77 800	84 400				
		850 000	1.062	1120	1720	2130	36 800	40 500	48 600	55 200	73 600	81 000				
		800 000	1.031	1075	1640	2030	35 100	38 600	46 300	52 600	70 200	77 200				
		750 000	.998	1025	1580	1940	33 600	36 900	44 200	50 500	67 200	73 800				
		700 000	.964	980	1490	1830	31 600	34 800	41 600	47 500	63 200	69 600	95 000			
		650 000	.929	920	1410	1740	30 100	33 000	39 700	45 000	60 200	66 000	90 000	99 000		
		600 000	.893	870	1330	1640	28 400	31 200	37 400	42 500	56 800	62 400	85 000	93 500		
		550 000	.855	810	1250	1530	26 400	29 000	34 900	39 700	52 800	58 000	79 400	87 000		
		500 000	.815	755	1160	1430	24 800	27 200	32 600	37 200	49 600	54 400	74 400	81 500		
		450 000	.772	700	1060	1320	22 800	25 000	30 100	34 200	45 600	50 000	68 400	75 000		
		400 000	.728	640	980	1210	21 000	23 000	27 600	31 400	42 000	46 000	62 800	69 000		
		350 000	.681	575	885	1040	18 900	20 800	24 800	28 300	37 800	41 600	56 600	62 000	94 000	
		300 000	.630	515	785	970	16 800	18 400	22 100	25 200	33 600	36 800	50 400	55 200	83 500	
		250 000	.575	450	685	840	14 500	16 000	19 100	21 800	29 000	32 000	43 600	47 800	72 500	
	0000	211 600	.528	385	605	750	13 000	14 300	17 100	19 500	26 000	28 600	39 000	42 700	65 000	[illegible]
	000	167 772	.470	330	508	625	10 800	11 900	14 200	16 200	21 600	23 800	32 400	35 600	54 000	[illegible]
	00	133 079	.418	280	425	527	9100	10 000	12 000	13 700	18 200	20 000	27 400	30 000	45 500	[illegible]
	0	105 560	.373	235	360	444	7700	8450	10 100	11 500	15 400	[illegible]	23 000	25 400	38 500	46 000
	1	83 694	.332	195	300	370	6400	7050	8420	9600	12 800	14 100	[illegible]	21 100	32 000	38 400
	2	66 358	.292	162	250	307	5300	5850	7000	7950	10 600	[illegible]	[illegible]	17 500	26 500	[illegible]
	3	52 624	.260	136	210	258	4460	4900	5880	6700	8920	9800	13 400	14 700	22 400	[illegible]
	4	41 738	.232	114	176	232	4000	4420	5300	6000	8000	8840	12 000	13 200	20 000	24 000
	5	33 088	.206	96	147	182	3150	3470	4150	4700	6300	6940	9400	10 400	15 800	18 800
SOLID	0000	211 600	.460	370	565	728	12 600	13 800	16 600	18 900	25 200	27 600	37 800	41 500	63 000	75 600
	000	167 772	.410	310	475	588	10 200	11 200	13 400	15 300	20 400	22 400	30 600	33 500	50 800	61 200
	00	133 079	.365	258	420	495	8550	9400	11 300	12 900	17 100	18 800	25 800	28 200	42 600	[illegible]
	0	105 560	.325	218	335	415	[illegible]	7900	9450	10 800	14 360	15 800	21 600	23 600	36 000	43 200
	1	83 694	.289	182	280	348	6020	6620	7950	9050	12 040	13 600	18 100	19 800	30 000	36 400
	2	66 358	.258	154	238	295	5100	5600	6750	7650	10 200	11 200	15 300	16 800	25 500	30 600
	3	52 624	.229	128	200	245	4250	4660	5600	6350	8500	9320	12 700	14 000	21 200	25 400
	4	41 738	.204	108	167	207	3580	3940	4700	5370	7160	7880	10 740	11 800	17 800	21 480
	5	33 088	.182	90	140	174	3020	3320	3970	4500	6040	6640	9000	9900	15 000	18 000

Formula (from Foster's Hand Book) *Amperes* = 1100 $\sqrt{\frac{TD^3}{R}}$ for stranded conductors, and *Amperes* = 1250 $\sqrt{\frac{TD^3}{R}}$ for solid conductors, where T = temperature rise is degrees C., D = diameter of conductor in inches, and R = resistance in ohms per mil foot at the final temperature. Based on an air temperature of 25 degrees C.

(absolute temperature of 65 degrees C.) have also been expressed in the form of k.v.a., three-phase values corresponding to various transmission voltages. Thus No. 0000 stranded bare copper conductors suspended in still air out doors at 25 degrees C. will carry 750 amperes with a temperature rise of 40 degrees C. (absolute temperature 65 degrees C.). If the transmission voltage is 220 volts, the corresponding k.v.a. value will be 285 k.v.a. three-phase and if the transmission voltage is 10 000 volts, 13 000 k.v.a. may be transmitted with the same temperature rise.

As indicated by foot notes the values of the table were calculated by formulas from Foster's Handbook as follows:—

$$\textit{Amperes} = 1100\sqrt{\frac{TD^3}{R}}\ \textit{for stranded conductor} \ldots (25)$$

$$\textit{Amperes} = 1250\sqrt{\frac{TD^3}{R}}\ \textit{for solid conductor} \ldots (26)$$

Where

T = Temperature rise in degrees C.
D = Diameter of conductors in inches.
R = Resistance of conductors in ohms per mil-foot at final temperature.

Inspection and Overhauling of City and Interurban Cars

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THE inspection and overhauling of city and interurban cars are usually divided into three classes; namely—light inspection, heavy inspection and general overhauling. The purpose of these inspections is to keep the cars and equipment in the best possible condition as to cleanliness and efficient and safe operation of mechanical and electrical apparatus; to supply satisfactory service to the traveling public; and to discover and remedy defects which, if not discovered in time, would cause failures on the road, possible accidents and heavy costs for repairs.

It is of vital importance to have an efficient and well-organized body of trained men to take care of these inspections. Therefore, a number of men should be chosen from the shop force to act as inspectors and each should be assigned a certain amount of work to be performed. It should be the aim of every inspector to keep his part of the equipment in as good and neat condition as possible. If for any reason, due to his negligence, car delays occur in service, he should be censured accordingly; and should delays continue to happen, that could have been prevented by him, he should be removed from inspection work.

LIGHT INSPECTION

Each city car should be shopped after running 1000 miles, which will be approximately every eight days, and each interurban car after running 2000 miles or approximately every ten days, and given a light inspection, consisting of the following:—

Car Bodies—Roofs should be examined for damaged canvas and necessary repairs made. Leaky roofs from other causes should be repaired. Deck sash should be examined and broken glass replaced. The deck sash operating mechanism should be examined and operated to see that the sash open and close freely.

Signal bells, strap-hangers, bell cords and hand straps should be inspected and any necessary repairs made. The signal bells should operate freely from each end of the car.

Car seats should be inspected for broken castings, loose seats and damaged covers and necessary repairs made. The seats should reverse freely. The footrests should be examined to see that none are missing. Curtains should be inspected and necessary repairs made so that the rollers will operate freely. Each curtain should be operated separately. All sash should raise and lower easily. Sash lifts and catches should be kept in first class condition. All broken window glass should be replaced. Ventilators (shutters) should be made to open and close easily. The entire inside of the car should be examined for projecting screws, etc., which might tear clothing, and any found should be repaired.

The register operating mechanism should be examined and put in first class condition.

The floors, including the vestibule, should be examined for broken or worn boards and any found should be replaced. Window guards should be kept in first class condition.

The Door and Step-Operating Mechanism should be examined and made to operate satisfactorily. Care should be taken that doors lock properly when in the closed position, also that all connecting pins are supplied with cotter keys, properly spread. Special attention should be given to step safety treads, which should be in first class condition. All moving parts of the mechanism should be oiled and greased.

Car Washing—The outside of each car should be washed with brush and cold water and rinsed. The floor of each car should be thoroughly swept and mopped with a solution of five gallons of water and one teaspoonful of disinfectant. The interior wood work, the seat cushions and frames and all glass ware should be washed with cold water and a sponge.

Fenders—Platform Gong—Draw Bars—Sanders—Fenders should be closely examined and kept in first class condition. They should not be painted on light inspection. Platform gongs should be oiled and gong must be tight on the frame. Each gong should operate freely. Draw-bars should be examined closely and left in good operating condition. The draw-bar carrier slides should be covered with a thin coat of grease. Each car should be equipped with a coupling bar, suspended from the

bottom of the car body by hooks. Sanders should operate satisfactorily and the hose should line up with the center of the rail.

Trucks and Brake Rigging—Trucks should be closely examined for loose bolts, nuts and rivets, and any found should be tightened. Also any broken truck casting should be replaced. The brake rigging on trucks and car body should be examined and care taken that cotter keys are not missing and are properly spread.

Brake shoes should be examined and any that are so worn that they will not last until the next inspection should be replaced

Motor axle bearing caps and gear case bolts should be examined and tightened, if necessary. Gear case hand hole covers should close tightly.

Hand brakes should be examined to see that they are in first class condition, special attention being given to the release. All points where trucks and brake rods chafe on their guides should be given a thin coat of grease.

Trolley bases should be oiled and kept in first class condition. The trolley pole should not be twisted and the wheel should line up with the trolley wire. Any wheels that are so worn that they will not run until the next inspection should be replaced with new ones.

Motors—Top and bottom commutator covers should be removed and the air-gap measured between field poles and armature with a gauge provided for that purpose. Should the gauge show an unsafe clearance, the foreman should be notified to have the armature removed and equipped with new bearings.

Brushholders should be examined and care taken that they are bolted tightly to the motor frame or yoke; also that hammers and springs are in good condition. The spring tension should be measured with a scale furnished for that purpose and should register from five to seven pounds tension. If for any reason the brushholders are removed, when they are replaced, the bottom of the brushholder should be approximately 1/8 to 3/16 of an inch from the commutator. A gauge should be provided for setting the brushholders. The porcelain insulators should be wiped with a cloth and any found cracked or broken should be replaced. The brushes should work freely in their guides, and if worn to such an extent that they interfere with the proper spring tension, or will not last until the next inspection, they should be replaced with new ones. It is very important that no brush should be cracked or broken.

The string band on the front of the commutator should be wiped off and given a coat of shellac, if necessary. All field coil and brushholder connections should be examined, also motor leads, to see that they are not chafing on the truck or motor frame. Dirty or rough commutators should be cleaned with fine sandpaper. The dust cap fastened to the armature bearing housing on the commutator end should be kept in place and securely fastened at all times. It is very important that all motor axle caps and gear case bolts be kept tight and they should be carefully inspected.

Electro-pneumatic Control and Motor Wiring—the first thing to do before a control inspection is started will be to open the main switch, which will prevent the car from being moved with any one under it, and the control can be safely operated for inspection purposes. The covers should be removed from the switch group, which should be blown out with compressed air, and other necessary cleaning done, particular attention being paid to the interlock contacts, to see that they are free from dirt. All control fingers should be examined and any found worn to such an extent that they will interfere with the correct operation of the interlock should be replaced with new fingers.

The arc horns, arc chutes, contact tips and switch shunts should be closely examined and any horns that are burned off, or shunts that give any indication of breaking should be replaced. Any arc chutes found burned or badly charred, should be replaced. The chutes removed should be taken to the repair bench, to be put in first class condition by the electrical repair men. Care should be taken in replacing arc horns that they do not strike the lower soap stone, which will cause breaking of the horns.

Main contact tips should be examined, and any worn unevenly or worn out should be removed and repaired, if possible. All tips should be lubricated by means of a rag dampened with compressor oil. Piston rod guides should be lubricated by giving each two drops of light oil. Each switch should be operated by pressing the pin on the top of each magnet valve to be sure the switches are working freely and any air leaks from valves or cylinders should be corrected. Any dirt on the piston insulator magnets or on the insulating surfaces of the switch group should be wiped off with a cloth.

The covers should be removed from each master controller and the controller thoroughly wiped out with a cloth. The drums and other contacts must be free from dirt and contact fingers examined for wear and proper contact.

The covers should be removed from the reverser and the reverser wiped free from dirt. The condition of the drums should be noted and, if found to be charred or burned, they should be scraped clean and shellaced. All low voltage contact fingers and contact surfaces should be free from dirt. All contact fingers should be examined for wear and proper electrical contact, and any rough contacts should be smoothed with a fine file. Main contacts should be lubricated in the same manner as switch group contact tips. The reverser should be operated in the same manner as the switch group and any leaky valves or cylinders repaired.

The reset switch should be cleaned and operated to the satisfaction of the inspector, care being taken that the overload trip resets.

The grid resistors should be examined to see that none of the grids are broken and that the wires are tight in their terminals. The through bolts should be

tightened, to take up any shrinkage in the insulation.

The entire control and reverser should be operated through a complete cycle from the master controller and the sequence checked.

The emergency check valve should be tested out in the following manner:—The compressor should be operated until the governor cuts out, then the main reservoir bled free of air. A test gauge should then be connected to the control emergency air tank and if the pressure remains constant, the check valve is in good condition. If the gauge shows a slow leakage, then the check valve should be removed and cleaned. It is very necessary that this valve be in first class condition and the emergency reservoir should show the same pressure as the main reservoir.

K Type Control and Motor Wiring—Covers should be removed and the dust blown out of the controllers. Adjust all fingers as to wear, tension and lift. Repair all damaged contact fingers and segments and replace those worn out. See that cylinders work freely, when operated from motorman's handle. Examine finger boards and see that all dirt and oil are cleaned away to prevent short-circuits. A few drops of oil should be applied to the cylinder bearings. Examine all leads, and see that they are firmly fastened to the terminals.

Circuit breakers should be examined and necessary repairs made. They should be wiped off with a cloth, contacts examined and any necessary adjustments made.

Grid resistors should be examined for broken grids and leads should be tight in terminals. The through bolts should be tightened to take care of any insulation shrinkage. Motor cables should be examined and cleated firmly to the car body.

Auxiliary Equipment—All lights should be tested and the burned out ones replaced. The light switches should be examined and any needed repairs made. Any defective light sockets should be replaced. Stove motors, switches and resistance should be examined and any necessary repairs made. All electric buzzers and push buttons should be kept in first class operating condition. Head lights should be cleaned and kept in good condition. Each car should be supplied with extra light, buzzer and compressor fuses.

The commutator covers should be removed from the compressor and all dirt cleaned from the brushholders and insulators. The brush tension should be checked and the brushes should work freely in their guides. The commutator should be examined for open circuits, and if rough or dirty it should be cleaned with fine sandpaper. The string band at the end of the commutator should be cleaned and, if no polish is visible, it should be shellaced.

Air Brake and Piping—All piping should be tested with soap suds and leaks repaired. The governor should be examined, cleaned and adjusted. It should cut out at 70 pounds and cut in at 55 pounds on city cars. On interurban cars it should cut out at 80 pounds and in at 65 pounds. The engineer valves should be operated and kept free from leaks. They should be cleaned and oiled every fourth inspection. The air reservoirs should be bled to eliminate accumulated oil and water. The amount of oil in the compressor should be examined. It should be visible at the top of the filling cups. The mushroom strainers, located on top of the floor on the inside of the car, should be removed and cleaned.

Lubrication—The free oil level in the armature bearing housings should be measured and maintained at a minimum level of one and one-half to two inches and a maximum level of three to four inches, depending upon the type of motor. Specific instructions should be given the inspector for each type of motor used. Similarly the oil level in the motor axle bearing should be maintained between one inch minimum and 2.5 inches maximum, depending upon the type of motor. Journal bearings need not be inspected at every light inspection but should be examined every fourth inspection. One gill of oil should be poured into the journal box as near the back end as possible, and care should be taken that all dirt and waste are cleaned from the seal before the journal box cover is closed. The side and center bearings should be given a light coat of grease.

HEAVY INSPECTION

Each city car, after it has made about 12 000 miles, or approximately every three months, and each interurban car, after it has made about 35 000 miles or approximately every six months, should be brought into the shops and given a heavy inspection, along the following general lines, in addition to all work regularly done during light inspections:—

Car Bodies—The outside of all wooden cars should be examined for any defects.

Door and Step-Operating Mechanism—All loose motion should be taken up. All bearings should be thoroughly oiled and chafing parts greased. It is very essential that the doors lock when in both open and closed positions.

Car Washing—The inside of the cars should be thoroughly washed with naphtha soap and hot water. The floor should be mopped as on light inspection. The outside of the car should be thoroughly scrubbed with a strong solution of linseed oil soap dissolved in hot water and the body then rinsed with a sponge and cold water. The inside and outside of the windows, including ventilators, should be cleaned thoroughly. The trucks and that part of the equipment underneath the car, visible from the side of the car, should be dry cleaned with a brush and then wiped with a piece of oily waste. All refuse should be removed from the window pockets and underneath enclosed paneled seats.

Fenders—The fenders should be painted with one coat of black asphaltum paint.

Truck and Brake Rigging—The journal box pedestal plates and the truck bolster swing motion hanger pins should be greased. The wheels should be gauged and those with sharp or thin flanges should be removed. Gears and pinions should be examined and those found

worn to a sharp edge should be removed. Journal bearings should be inspected and any found worn to ¼ inch thickness should be removed. Motor axle bearings should be removed if worn 3/16 of an inch on the diameter. The end play should not exceed ⅜ of an inch. All worn pins and bushings on the truck brake rigging should be replaced. Special attention should be given to see that mud guards are securely fastened to the car bodv.

Motors—The motors should be blown out with compressed air. Brushholders should be removed and the inside of the motor casing should be painted with an air drying insulating varnish. The front end of the armature and field coils should also be painted. The brushholders should be taken to the repair bench to be thoroughly cleaned and any necessary adjustments made.

Electro-pneumatic Control and Motor Wiring—The main ribbbon fuse should be removed and put back. This is necessary in order to keep the clamping blocks and screws in operating condition. If the fuse, at the blowing point, has any indication of heating and excessive scaling, it should be replaced with a new fuse.

The top cover of the switch group should be removed and the top of the switch group blown out with compressed air. The copper bolts holding the switches and blowout should then be tightened, if necessary, care being used not to stretch the bolts. All insulating surfaces in the switch group and reverser should be rubbed off with a rag and those parts that have not a reasonably clean polished surface, should be given a coat of shellac. One or two drops of oil should be placed on the pivot pins on which the switch arm, contact finger and piston hook. The bolts holding the shunts should be tightened, if loose. Special attention should be given to sluggish switches. These can be brought to normal operating speed by oiling the piston rod guides, or lubricating the piston with lubricating compound.

The upper and lower valve stems of the switch group and reverser should be removed, and if found gummy they should be washed in gasoline, special care being taken that each is returned to its own position, because each stem is ground to fit its own seat. All control contacts should be lubricated by wiping with a piece of cheese cloth, moistened with compressor oil. The covers of the switch group and reverser should be examined to see that the felt and insulation on them is in place and in good condition. The frames of the switch group, reverser and grid resistors should be tested for grounds with a bank of lamps connected to the trolley wire. If any are found to be grounded, the cause must be located and removed. The nuts holding the grid resistor frames together should be inspected and tightened if any are found loose.

The cover of the overload trip relay should be removed and any dirt on the inside cleaned out. It should then be tried out both by the reset switch and by a wire attached to the locking plunger. The screws holding the reverser fingers to the insulating base should be tightened if necessary. The master controller fingers should be examined for wear and adjusted to have a lift of 1/16 of an inch. This is also true of the switch group and reverser control fingers. The parts of the star wheel and interlocking mechanism of the master controller should be oiled, as well as the cylinder bearings.

K Type Control and Motor Wiring—The nuts holding the grid resistor frames together should be inspected and tightened if any are found loose. The star wheel and interlocking mechanism in the controllers should be oiled. All insulating surfaces in the controller should be rubbed with a rag and those parts that do not show a reasonable polish should be given a coat of shellac.

Circuit breakers should be opened and examined carefully for wear, dirt, loose parts or damage of any kind. The contacts should be smoothed up with a file, after which they should be lubricated slightly by applying a thin coat of vaseline. Arc chutes should be examined for burning and dirt. A drop or two of oil should be applied to the bearing pins to prevent rust. The circuit breaker setting should be correct and the tripping mechanism in good condition.

Auxiliary Equipment—The compressor brushholder should be removed and the motor blown out with compressed air. The front field coils in the armature should be wiped off with cheese cloth and painted. The string band in front of the commutator should be wiped off and given a coat of shellac. The brushholders should be examined and cleaned and those found defective taken to the repair bench. The armature should be measured for clearance with a gauge provided for the purpose.

Headlights should be cleaned and inspected, special attention being given to the polish of the reflectors.

Air Brake and Piping—The mushroom strainers should be taken apart and the curled hair washed in gasoline. During the operation of the compressor, attention should be given the suction and discharge valves; if any are not performing their duty, the cause should be located and remedied.

The brakes should be applied and engineer valve handle placed in the lap position to see that the brakes hold and that air is not leaking past the piston packing. Special attention should be given to the piping to be sure that all pipes are securely fastened to the car body and that they do not vibrate while the car is in operation.

Lubrication—Waste should be removed from the armature, motor axle and journal bearings and pulled apart, and all waste which appears glazy should be thrown away and new waste added when repacking. The oil should be brought to the level as maintained at light inspection. Gears and pinions should be lubricated with gear lubricating compound.

GENERAL OVERHAULING

Each city car, after running 48 000 miles or approximately one year and each interurban car after running 74 000 miles or about one year, should be brought

to the shop and receive a general overhauling. All work as done on light and heavy inspection should be included in the general overhauling, which will consist, in addition, of the following work:—

Car Bodies—All brass trimmings should be removed from the car and given a coat of statuary bronze finish. All seats and seat frames should be removed and necessary repairs made. All sash should be removed, necessary repairs made and then varnished. The entire car body should be closely examined for damaged or decayed wood and missing parts and necessary repairs made. Vestibules should be inspected and those found sagged to any extent or so that they will interfere with the operation of the doors should be jacked up and shimmed After painting has been completed, the car should be retrimmed.

Door and Step Mechanism—The entire mechanism should be dismantled and the worn parts replaced or bushed.

Car Washing—The inside and outside of the car should be thoroughly washed with a linseed oil soap solution and rinsed with cold water and a sponge. Seat frames and cushions should be washed with the same solution. The trucks and that part of the equipment underneath the car, visible from side of car, should be dry cleaned with a brush. After the car has been touched up and varnished, the windows should be cleaned, special attention being given to the removal of varnish or stains on the glass. Curtains should be removed and washed.

Fenders—Platform Gong—Draw Bars—Sanders—Regular work as done on light and heavy inspection should be performed at general overhauling.

Truck and Brake Rigging—The cars should be jacked up and the trucks removed and placed on the repair track where the motors should be removed. Brake levers and rods on the truck and car bodies should be removed, holes rebushed with hardened bushings and supplied with hardened pins if necessary. The elliptical springs should be removed and soaked in kerosene oil. A general replacing of worn parts and tightening of loose parts should be carried out.

Motors—Armatures should be removed from the frames, taken to the armature room and cleaned, necessary repairs made, tested, painted, properly dipped or rolled in a good grade of baking varnish and baked at least 24 hours, attention being given to loose bands and poorly soldered clips. Special attention should be given to see that commutators are undercut 3/64 inch, front V ring cleaned and well painted, rear of commutator sealed from dirt and that the commutator is tight.

Field coils should be removed, given a gasoline bath and painted with black air-drying varnish. The inside of the motor frames should be cleaned and given a coat of black air-drying varnish.

Brushholders should be removed and taken to the repair bench to be cleaned and repaired, special attention being given to worn parts and weak springs. When the brushholders are installed again in the motors, attention should be given the proper spacing and alignment. Armature bearing housings should be cleaned with kerosene oil and new armature bearings installed, if necessary.

Electropneumatic Control and Motor Wiring—The switches and blowout coils of the switch group should be removed and all the cables and insulating material painted or shellaced. The cylinders of the switch group and reverser should be thoroughly cleaned out and put together with a fresh supply of cylinder compound, special attention being given to the wear of the piston leathers. The air-gap and travel of the magnet valves should be checked and adjusted if necessary. The drums of the reverser and master controllers should be removed for painting of the interior and the drums.

K Type Control and Motor Wiring—The main and reverser cylinders should be removed and all insulating surfaces should be painted or shellaced. The cylinder bearings and controller handles should be bushed with steel tubing if necessary. The circuit breakers should be removed and taken to the repair bench, where they should be taken apart and thoroughly cleaned and painted and all worn mechanical parts replaced. After reassembling, the circuit breakers should be tested and their calibration checked.

Auxiliary Equipment—Light and heavy inspection work should be repeated.

Air Brake and Piping—The compressor should be removed from the car, taken apart and thoroughly washed out with gasoline. The armature and field coils should be removed and sent to the armature winding room to be cleaned with gasoline, tested and painted. Piston rings, connecting rods, crank shaft and bearings should be closely examined and necessary repairs made.

The brake cylinders should be taken apart, cleaned and lubricated. The engineer's valves should be taken apart, cleaned and worn parts replaced. The rotary valves should be reground if necessary. Engineers valve stems and handles should be bushed, if worn to any extent. The governor should be taken apart, cleaned and necessary repairs made. The main reservoir should be removed, given a hydraulic test of 125 pounds pressure and one coat of black asphaltum paint. The accuracy of the air gauges should be checked with a test gauge.

Lubrication—Work should be performed as outlined on heavy inspection.

Painting and Varnishing—The outside of the car should be touched up with color varnish and given one coat of clear varnish. The inside of the car should be touched up with color varnish and given one coat of clear varnish. The roof and floor should be given one coat of a good grade of roof paint. The seat frames should be given one coat of color varnish and the cushions one coat of seat varnish. The trucks and that part of the equipment visible from the side of the car should be given one coat of black asphaltum paint.

Armature Slot Wedges

F. J. Aimutis

ARMATURE wedges are commonly made of hard vulcanized fibre. As far as the electrical characteristics are concerned, armature wedges could be made of almost any non-magnetic material, such as wood, brass, bakelite, etc. The mechanical features are the chief points to be considered. Wooden armature wedges give fairly satisfactory results and are used in some types of motors and generators, but vulcanized hard fibre wedges are much more common. Wooden wedges of the usual dimensions break rather easily if cut across the grain. This breaking is a matter of concern only while the wedge is undergoing the process of manufacture, or the final step of putting it into the slot. If cut along the grain, the thin edges that fit in the grooves in the armature slot are likely to split off rather easily, due to the centrifugal force exerted by the armature coil behind them, even at comparatively low peripheral speeds. Wooden wedges do not vary much in size due to drying and absorbing moisture. This characteristic is a very desirable and essential factor in the case of wide slot armatures, such as the high speed turbogenerator. In exceptionally wide slot armatures either wooden or well treated fibre wedges are used. The latest development is the use of dried and varnish-treated fibre wedges.

Non-magnetic wedges, such as brass wedges, can be used with notable mechanical advantage. But if made of comparatively large size they get hot due to eddy currents. This heating does not injure the wedge itself but it adds so much more heat to the armature coil and, with the usual non-fire proof insulation, this would endanger the armature coil insulation. Moreover, such a metallic wedge has to be insulated from the armature core or it would short-circuit the core laminations and thus, to a considerable extent, would defeat the purpose of laminating the core. Metal wedges eliminate troubles due to having the wedges fall out of the slots, as they do not carbonize and, in the usual dimensions of the slot, expansion due to heating works in favor of making the wedges tight rather than loose.

Bakelite micarta wedges have been considered, and these offer considerable advantages due to the higher carbonizing temperatures. While thus far there has been no pressing need of bakelite wedges in the usual industrial motors and generators, this seems to offer a promising field for development.

Vulcanized hard fibre armature wedges are used in practically all direct current armatures at the usual commercial speeds with the usual non fire-proof insulation. Fibre is easily machined, withstands motor operating temperatures and mechanical stresses. In short, it has all the desirable and necessary properties. Vulcanized fibre is made of all cotton cellulose paper. This wholly cotton unloaded paper is passed over a heated cylinder and through a bath of zinc chloride at a temperature of about 40 degree C. It is then rolled over large heated drums to the required thickness, the zinc chloride hydrolizing the cellulose and gelatinizing the surface to such an extent that the paper unites and forms an almost homogeneous mass.

The "green fibre" is then washed in zinc chloride baths of progressively diminishing concentration at room temperature until it is commercially pure, i. e., contains a very small percentage of chlorine. This process is very slow. One-quarter inch fibre, for instance, requires three to four weeks for washing, and two inch fibre, six to eight months. The wet fibre is dried at a temperature of about 50 degrees C. after which it is pressed and usually calendered. The finished product, which has shrunk to one half its original thickness, is a homogeneous, tough, hornlike material.

Fibre is not water-proof but is not injured by immersion in water. Neutral salts are also without harmful effect but most mineral acids in time cause disintegration. Organic solvents, such as ether, and all oils are without effect on fibre Averaged results of a few comparative and typical tests are given in Table I. These tests show approximately the characteristics and properties of the kind of fibre that is used for the armature wedges.

TABLE I—COMPARATIVE TEST ON TYPICAL SAMPLES OF HARD VULCANIZED FIBRE

Thickness, inch	1/8	1/8
Specific gravity	1.10	1.48
Chlorine content, percent	0.20	0.03
Shearing stresses, lbs. per sq. in.	9000	13 000
Crushing strength	33 000	43 000
Tensile strength	8000	13 000
Breakdown voltage	12 500	50 000

It has been demonstrated by test that fibre does not quite regain its original flexibility after being dried completely. It becomes rather hard and brittle, although it may regain its original amount of moisture. Fibre reabsorbs moisture in about two-thirds of the time required to expel the same amount of moisture without carbonizing the fibre.

Vulcanized fibre shrinks with the removal of moisture and expands with the absorption of moisture. Tests were made on a few samples of fibre of 0.1 in. thick and 0.5 inch wide to determine the amount of shrinkage due to removal of moisture and the amount of expansion due to absorption of moisture. On these particular samples the average shrinkage and expansion in width was approximately one mil per one percent change in moisture. The shrinkage and expansion in thickness was much greater than in width.

Tests were made on a few samples of fibre of different thickness, color, quality and at different temperatures to determine the breakdown voltage per unit of

thickness. The voltage increases with increase of temperature on thin samples and decreases with increase of temperature on thick samples when heated for a short time only. This is because the small amount of zinc chloride in solution causes the resistivity to decrease with increase in temperature in the thicker samples, while in the thin samples moisture is rapidly driven out, nullifying this effect.

The breakdown voltage per unit thickness is also a function of the extent to which gelatinization of the individual piles of paper has been carried. Gray fibre is made from paper of the natural color, with no coloring matter. Black fibre contains a small amount of lamp black or other coloring matter. Red fibre is colored with various grades of oxide of iron. Any loading material placed in the paper, from which the vulcanized fibre is made, tends to interfere with the chemical treatment and the result is a less homogeneous material. Coloring matter acts as a loading material and produces a slightly more "papery" fibre, which usually has a higher breakdown voltage because of the greater degree of lamination. Thus a colored fibre may have a higher breakdown voltage per unit thickness than gray fibre, although the coloring matter in itself is a conductor.

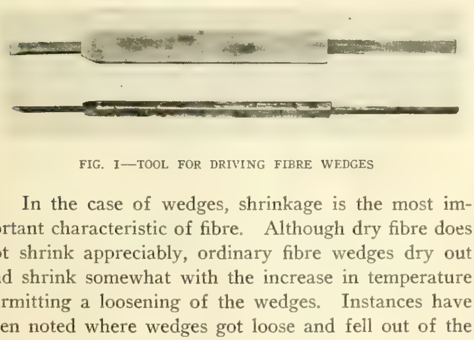

FIG. I—TOOL FOR DRIVING FIBRE WEDGES

In the case of wedges, shrinkage is the most important characteristic of fibre. Although dry fibre does not shrink appreciably, ordinary fibre wedges dry out and shrink somewhat with the increase in temperature permitting a loosening of the wedges. Instances have been noted where wedges got loose and fell out of the armature slots. The number of such cases, however, is practically negligible. To overcome the disadvantage of loose wedges some of the wedges are made of dry and treated fibre. This practice proved to be fairly successful and is being applied in the cases of wide wedges.

The fibre is received from the manufacturer in large sheets. These sheets may be stored as received or may be dried completely in ovens at about 115 degrees C., then varnished and stored.

In making wedges from the undried fibre the first step is sawing narrow strips along the grain of the fibre, the strips being of the width of the wedge. These strips are then passed through a milling machine which cuts off the corners of the rectangular strip and shapes its edges to the required form. The long strips, already shaped to the required form, are next cut into short pieces about three inches to ten inches long, as the case may require. One end is then beveled to make it easier to put the wedge into the slot. The finished wedges are dipped into paraffine for about ten minutes.

In making wedges from the dry fibre, the first operation is sawing narrow strips along the grain of the fibre. The strips are then cut into the required lengths, and the corners ripped off on a planer. The dry fibre is too hard to be worked on the milling machines and in most cases the dry wedges are intended for the more refined machines and the corners are shaped accurately, which cannot be done easily on a milling machine. The end is beveled, and the strips are dried at about 125 degrees C. for about twenty minutes and are then dipped into melted paraffine for about two hours.

The wedges are put into the armature slots from a special shuttle such as shown in Fig. 1. This tool is simply a bar of steel with a rectangular hole through it lengthwise, large enough to take in the wedge, and a bar of the same size as the hole. The bar is inserted behind the wedge and driven with a mallet. This shuttle guides the wedge into the slot and prevents it from buckling and breaking.

The object of the armature wedge is to keep the armature coil in the slot. Thus the vulcanized fibre or wood wedges are good for low or moderate peripheral speed machines only. On the high peripheral speed machines, armatures are banded with wire bands and no wedges are used.

On comparatively small diameter armatures no wedges are used, the coils being held in the slots by wire bands. In this case the teeth are very tapered, i. e., teeth of the usual length may be sufficiently wide at the peripheral end but at the inner end they usually are very narrow and the longer they are the narrower they are at the root. The space required for the wedge is about 3/32 inch. This 3/32 inch cannot well be spared in length as it would make the teeth too narrow at the root. Narrow teeth are undesirable for magnetic reasons.

In high temperature machines, such as steel mill motors, the maximum operating temperature may be as high as 115 degrees C., which approaches close to the carbonizing temperature of vulcanized fibre. In such cases vulcanized fibre wedges would shrink considerably and probably fall out of the slots. Hence for such machines no wedges are used, the armatures being banded with wire bands.

In alternating-current machines, metal wedges are sometimes used. In one type of wedge which has been extensively used, the outer parts are made of steel and the middle part of brass. The steel portion is intended to produce the effect of a semi-closed slot. The brass portion is intended to complete the wedge and yet not close the magnetic circuit. These wedges could be used in the direct-current commutating-pole machines but the advantages gained in reducing the effective air-gap would be overbalanced by the increased difficulties in commutation.

The Thermal Conductivity of Insulating and Other Materials

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Although numerous experimenters have been interested in making thermal conductivity measurements, little data is available for such materials as are used in the construction of electrical machinery. The most important work on such insulating materials thus far available was done by Symons and Walker.* The materials tested were special and consequently the values obtained can not be taken as applicable to similar materials used in the construction of electrical machinery in this country. The investigations herein described were undertaken, therefore, to obtain determinations of the thermal conductivity of insulating and other materials, the values of which are of direct interest to those concerned with the heat problem in electrical apparatus. As a preliminary step it seemed worth while to try the thermal bridge method suggested by Prof. E. F. Northrup.**

THE NORTHRUP THERMAL BRIDGE

The bridge, shown in Fig. 1, consisted of two soapstone cylinders each 4⅝ in. in diameter, one being 8½ in. long and the other 3 in. long. Each cylinder consisted of an inner core 1⅝ in. diameter surrounded by a concentric cylinder having a wall thickness of 1⅜ in. The two faces along *MN* separating the two parts of the apparatus were ground so as to fit very closely. A spiral groove was cut in the top of the longer cylinder *E* and a heater wire placed in this groove as indicated. Small holes, *1*, *2*, *3*, etc., were drilled at right angles to the axis of the cylinders through the outer wall and into the central core as indicated. Copper-constantan thermocouples made of 0.005 in. wire were inserted in these holes for the purpose of determining the temperature gradient along the cylinders. The lower part of the apparatus *F* was placed on a brass box which served as a cold temperature reservoir when kept filled with water and ice or when water was kept circulating through it. The heat generated at the top would flow down the core and outer wall through the junction *MN* to the reservoir. The purpose of the core and surrounding wall was to insure a uniform flow of heat through the core. Felt was placed around the outer cylinder to further prevent undue loss of heat from the surface of the apparatus.

THEORY AND METHOD

If the distance from thermocouple *1* to *5* is made the same as that from *2* to *8*, and the conditions are such that a uniform temperature drop exists along the core, the thermal conductivity of a material placed in *MN* can be determined in terms of soapstone. First, suppose the above conditions to exist when there is no specimen in *MN*. Then the temperature drop will be uniform along the apparatus, as can be tested by the thermocouples. When a sample is inserted in *MN*, and the temperatures of *1*, *5*, *2* and *8* measured, the drop between *2* and *8* exceeds that from *1* to *5* by an amount equal to the drop through the sample. The soapstone equivalent of the sample is then readily calculated from the temperature drop through the sample and the temperature drop per unit length along the soapstone. This is dependent on the assumption that the drop is uniform along the soapstone and that there is no tem-

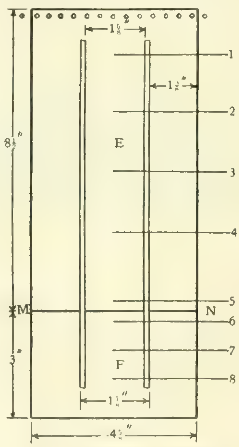


FIG. I—THERMAL BRIDGE

perature drop across the junctions of sample and soapstone at *MN*. In the actual experiment, the procedure was slightly different, as the distance from thermocouple *1* to *5* was not exactly the same as between *2* and *8*. As shown in Fig. 1, several thermocouples were inserted along the cylinder; and then from the curve between temperatures and distance from the upper thermocouple, the soapstone equivalent of the sample under test was readily determined. The thermo-electromotive forces of the thermocouples were measured by means of a thermocouple potentiometer and their equivalent temperatures obtained by reference to a calibration curve previously determined for the thermocouple wire used.

DIVISION DROP

If the two parts of the apparatus are fitted as closely as possible together, thus having no material be-

*British Institute of Electrical Engineers Vol. 48, p. 674, 1912.

**Amer. Elec. Chem. Soc. Jour. No. 24.

tween them at MN, and the temperatures as indicated by the thermocouples measured, a curve such as is shown in Fig. 2 represents the temperature distribution along the cylinders. The positions of all thermocouples are measured from the uppermost one. There is a very marked temperature drop at the division between the two parts of the apparatus, equivalent to 2.5

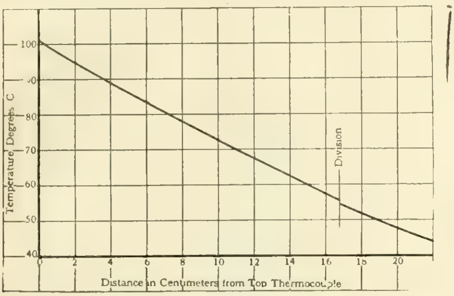


FIG. 2—TEMPERATURE DISTRIBUTION ALONG THE CYLINDERS

degrees C for this particular temperature distribution. This is about 4.4 percent of the total drop between thermocouples *1* and *8*. A sheet of paper 0.001 in. thick was then inserted which caused a slight increase in this temperature drop, although it by no means doubled it. Several things were then tried, to see whether the drop could be eliminated, either entirely or in part. It was found that by putting vaseline or glycerine between the surfaces *MN*, this division drop was almost, if not entirely avoided. This was true at least for relatively small temperature gradients. Fig. 3 illustrates this point very clearly. This curve was obtained when the division *MN* was well lubricated with vaseline.

To test whether the vaseline soaked into the soapstone sufficiently to affect the results, two rings and discs were cut from the same piece, one ring and one disc being thoroughly soaked in hot vaseline, and then the temperature gradients were obtained both with the vaseline soaked ring and disc inserted in *MN* and again

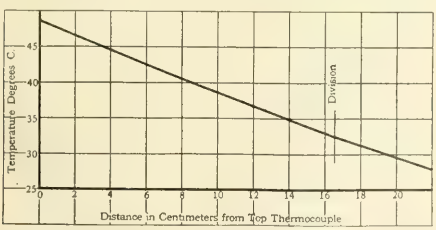


FIG. 3—TEMPERATURE DISTRIBUTION WITH DIVISION LUBRICATED WITH VASELINE

with the unsoaked ones in the same position. No noticeable difference existed between the two cases as the temperature gradients along the apparatus and through the disc were identical.

SOAPSTONE EQUIVALENT OF PARAFFINED FISH PAPER

Discs and rings were cut from 0.015 in. paraffined fish paper so as to fit the core and surrounding ring at the junction *MN* of the apparatus. The temperature gradient along the apparatus was determined when different numbers of sheets (discs and rings) were in position *MN* for various temperature differences between the hot and cold ends. A typical set of observations is represented by the curve in Fig. 4. The ordinates are the temperatures in degrees centigrade corresponding to the respective distances of the thermocouples *1*, *2*, *3* etc. measured from couple *1*. Curve *1* was obtained when the sample was composed of six sheets and curve *2* for ten sheets of 0.005 in. paraffined fish paper. Vaseline was used between the sheets in order to diminish the division drop as much as possible. Sufficient pressure was applied to the top of the apparatus to insure good contact between the surface of the constitutents of the sample and the soapstone. The values of the soapstone equivalent of one inch of paraffined fish paper obtained from the curves in Fig. 4 were 32.8 in. and 32.0 in. respectively. That is, one inch of paraffined fish paper composed of sheets 0.015

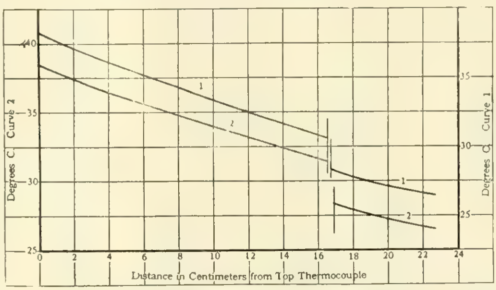


FIG. 4—TEMPERATURE GRADIENT WITH PARAFFINED FISH PAPER IN THE DIVISION

Curve *1* with six sheets and curve *2* with ten sheets.

in. thick would have a thermal resistance equivalent to the above values of soapstone. These values of the soapstone equivalent of fish paper were obtained from the curves in Fig. 4 as follows:—The drop through the sample *1* is 2.5 degrees C. and hence the drop per centimeter is this value divided by the thickness of the sample, that is 2.55/0.2286 or 11.15. The average temperature gradient obtained from the slope of the curve just above and below the sample is 0.350 degrees per centimeter. Therefore one cm. of the fish paper is equivalent to 11.15 ÷ 0.350 or 32.8 cm. of soapstone; or one inch of fish paper will have the same thermal resistance as 32.8 inches of soapstone.

Similar results, obtained for other samples composed of different numbers of sheets, are given in Table I. These results are all for 0.015 in. paraffined fish paper. As can be seen from the table, this method gives a wide variation in results. Various factors produce these variations, one of which is due to the fact that the temperature does not fall uniformly along the sample, heat being lost by radiation, conduction and convection from the inner core to the outside wall. This makes the slope of the curve, which determines the value of

the temperature gradient, quite uncertain, especially just above and just below the sample. Consequently the final results which depend upon these gradients will vary considerably. This large variation in results made it quite evident that it would be advisable to attempt the work by the use of some other method. The one described in the following section was found very satisfactory. The above method has the disadvantage also of being an indirect one which would necessitate a separate determination of the thermal conductivity of soapstone itself. This however would have been a small matter had the results been in close and satisfactory agreement. Such results as are recorded in Table I by no means fulfill these conditions.

THE THERMAL METER

A sketch of the "thermal meter" used is shown in Fig. 5. It consisted essentially of an electric heater H constituting two hot equitemperature surfaces or sources of heat and two cooling chambers E, E (one

TABLE I—SOAPSTONE EQUIVALENT THERMAL RESISTIVITIES OF PARAFFINED FISH PAPER

No. Sheets in Sample.	Total Thickness of Sample in Inches.	Av. Temp. of Sample Degrees, C.	Total Drop from Couple 1 to 8.	Drop in Sample	Soapstone Equivalent
5	0.077	29.7	11.5	2.58	37.4
2	0.030	29.6	10.6	1.05	37.5
6	0.088	33.3	11.7	2.55	32.8
10	0.155	25.7	11.8	3.66	32.0
4	0.060	30.0	11.2	1.70	27.2
15	0.221	28.0	12.0	4.25	24.7
20	0.305	28.5	14.4	6.30	28.2
15	0.228	28.6	14.0	5.45	33.4
10	0.150	27.7	12.6	3.58	27.2
5	0.075	48.5	55.7	10.50	32.6

on either side of the heater) or cold constant temperature surfaces. The heat generated in H passes laterally through the samples I, I of a given material to the cold reservoirs E, E. The heater was made from two discs of soapstone nine in. in diameter and three eighths in. thick. Each disc had a spiral groove of three sixteenths in. pitch cut in one face. A heater wire of No. 21 constantan was wound and cemented securely in the groove of each disc, and then the discs were cemented together with the sides containing the heater wire adjacent. The two heating elements in the two discs were joined together at the center by means of a peg in one disc being pushed into the spring contact in the other. Potential leads were brought out from each heating element at points two inches from the centers. It was later found that potential leads fastened to the heating elements at the points where the wire started in the outer terminals of the spirals served equally well, since the temperature coefficient of resistance of the constantan wire is very small and furthermore the temperature of the heater was constant over its entire face. Extra turns of wire were wound around the outer edge of the heater in order to prevent the loss of the heat generated in the heating element proper through the edge of the heater. After several trials, it was found that this procedure gave a heater which had a very constant temperature over its two faces even up to the outer edge.

Two samples of the material to be tested were always used, each being nine inches in diameter and from 0.1 to 0.75 in. thick depending upon the nature of the material. One sample was placed on each side of the heater I, I, Fig. 5. Extra discs of lagging of the same material as the sample or some other suitable material, were placed on each side of the sample, as shown by the shaded portions in Fig. 5. This made the ultimate drop at high temperatures less than it otherwise would have been, and likewise gave a wider range of mean temperature. The faces of the cold reservoirs E, E, constituting the cold equitemperature surfaces, were made of heavy brass having a diameter of ten inches. The samples, heaters and cold reservoirs were held together securely by means of bolts extending between these two plates. At first strong spiral springs were used around these connecting bolts to insure uniform pressure, but it was found later that equally satisfactory results could be obtained by merely turning down the nuts until the samples were drawn tightly together. Thermocouples of five mil copper constantan wire were inserted on each side of the samples I,I under test. Great care was taken in order to insure good contact between the sample and the thermocouple junction. Two couples were placed on each side of a sample, one at the mid point and another about 1.5 inches from the center. The electromotive force of the couples, (the cold junction being always kept at zero degrees C.) was measured by means of a thermocouple potentiometer. The current in the heater was likewise measured by the same potentiometer by measuring the drop through a standard resistance placed in series with the heater. The potential drop per unit length of heater wire was also measured by means of the potentiometer. This necessitated placing a high resistance in parallel with the heater and then measuring the potential drop across a small fraction of this. The current was supplied by a storage battery and consequently remained steady. The cold equitemperature surfaces E, E were maintained so by having water circulating through them continuously. The outer edges of the samples and heater were surrounded by felt in order to prevent undue loss of heat from the edges of the heater and samples.

In order to facilitate the work, a second apparatus having the same parts as the one described above was constructed, the only difference being that the heater, etc. were of square cross-sections. This heater was made of soapstone slabs 12 inches square. The heater wire, of No. 21 constantan, was wound back and forth in parallel slots three sixteenths in. apart in each of the parts of the heater. This made its construction quite easy. The elements of the two parts of this heater were joined in parallel, as its resistance would have been too high for the available voltage had they been in

series. The potential leads of this heater were joined at the ends of a wire in a single groove thus measuring the drop in a 12 inch length of the wire. Four sets of potential leads were inserted (two in each half) and the average of the four potential drops was used in calculating the drop per unit length of heater wire. As for the round heater, extra turns of wire were put

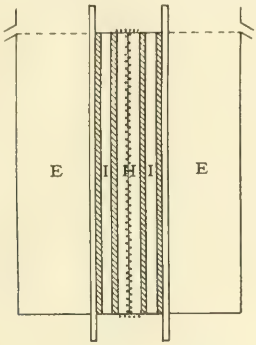


FIG. 5—THERMAL METER

around its outer edges to insure a uniform temperature source. Great care was taken to have the same amount of resistance in each element of the heater, since they were joined in parallel. The faces of the cooling reservoirs were of cast brass 13.5 in. square by 1 inch thick. This, being heavy, avoided any buckling when bolted together over the heater and the materials tested. Identical results were obtained with the two pieces of apparatus for a given material.

THEORY AND METHOD

The chief advantage of this method of determining thermal conductivities is the ease with which the quantities involved are measured. When heat passes continu-

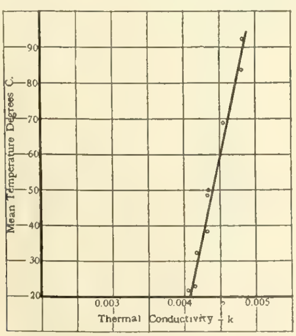


FIG. 6—TEMPERATURE COEFFICIENT OF TREATED FULLERBOARD

ously from one plane constant-temperature surface to another parallel to it, the quantity of heat flowing per second is given by the relation,— $Q = \frac{A\,k\,(t_2-t_1)}{d}$ where k the thermal conductivity of the intervening medium, d its thickness or the distance between the constant temperature surfaces, A the area through which the heat passes, and t_2, t_1 the temperatures of the hot and cold surfaces respectively. This formula readily lends itself to the calculation of k. The other quantities are readily measured in the above described apparatus. Q is determined from the current in the heater wire and the potential drop per unit area of heater. The latter is readily calculated from the constants of the heater and the potential drops between the fixed leads mentioned in the preceding section. Half the heat generated must pass laterally through each sample. The distance d is the average thickness of each sample. The area A can be taken as any desired value, preferably unity. This is possible only since the resistance of heating elements per unit length is constant, it being constantan with a practically constant temperature. The temperature t_2 and t_1 are the mean values of the temperatures for the hot and cold sides of both samples, as determined by the thermocouples. The thermocouples (copper-constantan) were carefully calibrated so that the temperatures corresponding to the microvolts measured from the calibration curve could readily be obtained. One rather serious disadvantage of this method of measur-

TABLE II—THERMAL CONDUCTIVITY OF 0.030 INCH TREATED FULLERBOARD

No. of Component Sheets	Thickness d in Inches	Hot Side Temp. t_2 °C	Cold Side Temp. t_1 °C	Mean Temp. °C.	Conductivity k in Watts/In. / °C.
7	0.230	29.15	18.10	23.62	0.00414
7	0.230	47.10	29.40	38.25	0.00432
7	0.230	59.45	37.15	48.30	0.00433
7	0.230	84.00	53.07	68.54	0.00458
7	0.230	102.60	65.05	83.82	0.00484
7	0.230	26.85	16.15	21.50	0.00407
7	0.230	40.87	24.20	32.54	0.00418
7	0.230	62.65	37.65	50.20	0.00436
7	0.230	115.20	70.30	92.75	0.00486

ing thermal conductivities is that it requires a long time to establish the temperature equilibrium which is absolutely requisite in such measurements. For the apparatus used here no observations were taken under 3.5 hours heating and nearly all measurements were taken after some 6 to 7 hours heating. This latter time was quite sufficient for equilibrium of temperature distribution to be fully established.

The samples of the materials tested were usually composed of one or more sheets. Extreme care was taken to eliminate the air between the surfaces of the component sheets by the use of vaseline, shellac, carpenter's glue, etc. By the use of such materials the drop between component sheets was made negligible or at least of the same order of magnitude as the drop through the same distance in the material itself. This was due to the fact that the thermal conductivities of such materials as glue, when dried, differ but little in order of magnitude from those of the sheet materials dealt with. In making up a sample, that material was used to make good contact between the components which lent itself most readily to the case in hand.

RESULTS

A typical set of results for samples made up from 0.030 in. fullerboard is given in Table II. By plotting the values of the mean temperatures as ordinates and the corresponding values of the thermal conductivity k as abscissae, it is possible to get a measure of the temperature coefficient of thermal conductivity. These values in Table II are plotted in Fig. 6 and a straight line representing the general slope drawn through the points. Such a line corresponds to the relation:—

$$k_t = k_o \ (1 + at)$$

Where k_t and k_o are the thermal conductivities at temperatures, t and o, respectively, and a is the temperature coefficient. As is shown, the value of a for this sample is about 0.0030.

In the manner outlined above the thermal conductivity measurements have been made for a large number of materials. The values obtained are recorded in Tables III, IV, V, and VI and are expressed both in calories /cm/ degree C. / sec. and in watts /in./ degree C. The value is also given for a definite temperature such as 20 degrees C. as well as for an average range of 20 to 80 degrees. The temperature coefficient is also recorded as determined from curves similar to the one shown in Fig. 6. It is to be observed that all samples did not show a temperature coefficient. This is doubtless due to the changing characteristics of the samples. Thus it is highly possible that the increase in the thermal conductivity due to an increase in temperature is counteracted by a corresponding increase in the thermal resistance due to the change in the surface contacts, and likewise an increase in air pockets. Besides measuring the thermal conductivity transversly for sheet material, measurements have been made as shown by the tables of the longitudinal conductivity along the laminations. The samples for this latter work were prepared for the one apparatus by winding discs of the material nine inches in diameter, and for the other apparatus by cutting the material into strips and then forcing them tightly together in a special press. By coating the edges of the strips, while in the press, with glue they could be held together in a square sample and later placed in the apparatus. It is interesting to note that the ratio of the longitudinal to the transverse conductivity is much greater for the mica combinations than for the other insulating materials. This is due to the influence of the mica, whose longitudinal conductivity is so much better than its transverse. The same ratio has its least value for such materials as varnished cambric and black bias cloth. For these materials, there is less difference between the transverse and longitudinal construction than in the mica compounds.

Results were obtained also for a number of granular and powdered materials. In order to make these measurements toroidal rings were made of pine wood, one-half in. wide, one-half in. thick and having an internal diameter slightly less than nine in. The powdered materials were placed within these rings between sheets of paper glued to the sides of the rings. The thermocouples were attached adjacent the material by means of shellac to the inner sides of the papers glued to the rings.

Results were also obtained for the transverse thermal conductivity of 0.0172 in. carbon sheet steel and for 0.014 in. silicon sheet steel. The values obtained are slightly greater than those obtained by other observers for similar materials. Attempts were made to detect the change

TABLE III—THERMAL CONDUCTIVITIES OF FIBROUS INSULATIONS

Material	Thickness of Sample, Ins.	Sp. Gr.	Direction of Heat Flow	Temp. °C	Cal /Cm / °C /Sec. $\cdot 10^{6}$	Watts /In / °C $\cdot 10^{5}$	Temp. Coef $\cdot 10^{4}$
Fish Paper	0.212	1.06	Trans.	20	410	435	19
0.010 In.				20-85	433	462	
0.010 In.	0.748	1.06	Long.	20	1150	1222	19
				20-80	1215	1290	
0.023 In.	0.222	1.03	Trans.	20	482	512	24
				20-85	517	548	
0.056 In.	0.355	1.01	Trans.	20	567	602	21
			Trans.	20-80	600	638	
Paraffined Fish Paper	0.211	1.06	Trans.	20	460	489	18
0.007 In.				20-80	483	513	
0.015 In.	0.225	1.13	Trans.	20	520	553	
				20-90	525	558	
0.038 In.	0.150	1.15	Trans.	15-30	494	525	
	0.299						
Treated Fullerboard							
0.020 In.	0.230	1.39	Trans.	20	384	408	30
(dark)				20-90	418	444	
0.030 In.	0.500	1.15	Long.	20	1450	1540	50
(dark)				20-80	1650	1750	
0.056 In.	0.227	1.09	Trans.	20	357	380	30
(green)				20-100	396	421	
0.125 In.	0.254	0.95	Trans.	20	339	361	16
(green)				20-80	350	372	
Untreated Fullerboard							
0.015 In.	0.232	1.38		20	640	681	
			Trans.	20-80	641	682	
0.30 In.	0.216	1.26	Trans.	20	610	649	9
				20-80	628	667	
0.30 In.	0.500	1.26	Long.	20	1500	1590	17
				20-80	1580	1680	
0.010 In.	0.210	1.39	Trans.	20	622	661	10
				20-90	690	735	
0.056 In.	0.217	1.15	Trans	20	465	495	60
(light grey)				20-60	515	548	
0.056 In.	0.500	1.15	Long	20	1520	1620	26
(light grey)				20-80	1650	1750	
0.125 In	0.365	1.01	Trans.	20	347	369	33
(light grey)				20-80	387	412	
0.125 In.	0.365	1.01	Trans.	20	507	540	16
(light grey) soaked in H. F. Oil				20-80	543	577	
0.125 In.	0.520	1.01	Long.	20-80	1230	1310	
Varnished Cambric (tacky)							
0.009 In.	0.263	1.17	Trans.	20	517	550	
				20-95	544	578	10
0.009 In.	0.694	1.17	Long	20	1027	1093	
				20-100	1046	1113	5
Varnished Cambric (dry)			Trans	20	516	549	
0.009 In.	0.275	1.24		20-90	532	565	9
Cement Paper, Plain			Trans	20	304	323	
0.015 In.	0.216	0.62		20-90	322	342	17
Treated Cement Paper			Trans	20	372	395	
0.018 in.	0.221	1.02		20-80	395	420	21
Black Bias Cloth							
0.009 In.	0.209	1.26	Trans.	20-100	600	621	
0.009 In.	0.782	1.26	Long	20	915	975	
				20-100	1027	1091	50
Micarta			Trans.	20	606	645	
0.125 In.	0.247	1.36		20-90	620	660	6

TABLE IV—THERMAL CONDUCTIVITIES OF MICA COMBINATIONS

Material	Thickness of Sample, Ins.	Sp. Gr.	Direction of Heat Flow	Temp. °C.	Cal /Cm / °C /Sec. × 10⁻⁶	Watts /In / °C × 10⁻⁵	Temp. Coef. × 10⁻⁴
Mica Tape							
0.006 In.	0.201	1.06	Trans.	20-80	630	670	
0.008 In.	0.229	1.12	Trans.	20-80	630	670	
0.006 In.	0.768	1.06	Long.	20-80	3470	3680	
Cement Paper and Mica							
No. 226	0.223		Trans.	20	443	472	
				20-80	462	491	14
No. 227	0.1985		Trans.	20	465	494	
				20-100	498	530	15
No. 247	0.225		Trans.	20	501	533	
				20-80	522	555	16
No. 227	0.512		Long.	20	2230	2370	
				20-80	2360	2510	20
Kraft Paper and Mica							
No. 312	0.220		Trans.	20-100	545	579	
No. 312	0.520		Long.	20	2680	2830	
				20-100	2840	3020	16
Fish Paper and Mica							
No. 230	0.195		Trans.	20-100	483	514	
No. 232	0.233		Trans.	20-100	475	505	
No. 233	0.237		Trans.	20-100	451	481	
Pressed Mica Plate							
0.041 In., White	0.201	2.34	Trans.	20-100	623	663	
0.041 In., Yellow	0.203	2.41	Trans.	20-100	550	585	
0.032 In., White	0.1915	2.32	Trans.	20-100	675	718	
0.032 In., Yellow	0.1915	2.41	Trans.	20-100	580	617	
0.025 In., White	0.1995	2.43	Trans.	20-100	725	771	
0.025 In., Yellow	0.1996	2.26	Trans.	20-100	612	650	
Micarta Folium							
No. 249	0.233		Trans.	20-100	553	588	
No. 249	0.569		Long.	20-100	2700	2870	

TABLE V—THERMAL CONDUCTIVITIES OF MISCELLANEOUS MATERIALS

Material	Thickness of Sample, Ins.	Sp. Gr.	Direction of Heat Flow	Temp. °C.	Cal /Cm / °C /Sec. × 10⁻⁶	Watts /In / °C × 10⁻⁵	Temp. Coef. × 10⁻⁴
Hard Rubber	0.380	1.19	Trans.	25-50	380	404	
White Fibre	0.383	1.22	Trans.	20	663	705	
				20-80	695	728	12
Woods							
White Pine	0.519	0.45	Across Grain	20-120	255	271	
White Pine	0.732	0.45	Along Grain	30-80	613	652	
White Oak	0.516	0.60	Across Grain	20-80	455	484	18
White Oak	0.754	0.60	Along Grain	40-70	944	1003	
Maple	0.733	0.72	Along Grain	20	1015	1078	
		0.72	Along Grain	20-80	1037	1100	8
Maple	0.508	0.72	Across Grain	20-80	434	461	
Asbestos							
⅜ In. Sheet	0.344	0.894	Trans.	22-80	395	420	
0.025 In. Paper	0.306	0.98	Trans.	20	345	367	
				20-100	375	399	24
0.035 in. Cloth	0.356		Trans.	20	666	708	
				20-80	685	728	14
Asbestos Board	0.507	1.93	Trans.	20-90	1950	2080	14
				20	1780	1890	
Plate Glass	0.252	2.49	Trans.	20	1786	1900	
				20-100	1945	2070	18
Plate Glass	0.289	2.60	Trans.	20	1905	2024	
Plate Glass	0.289		Trans.	20-120	2016	2142	12
Soapstone	0.715	2.87	Trans.	70-130	8000	8500	
Sil-O-Cel	0.977	0.495	Trans.	30-150	262	279	15
Brick				30	242	258	
Powdered	0.955	0.15		30-150	242	258	
Sil-O-Cel				30	208	222	31
Wool Felt	0.98	0.15	Trans.	40-100	175	186	76
Dark Grey				40	149	158	
Solid	1.04	1.58		50-130	110200	117200	12
Graphite				50	105500	112200	
Powdered							
Graphite	0.476	0.70		40-100	3200	3400	48
				40	2850	3030	
Through 20 mesh onto 40 mesh							
Powdered Graphite	0.476	0.42		40-110	1007	1080	40
Through 40 mesh				40	922	980	
Powdered Graphite	0.476	0.48		40-110	482	513	34
Through 100 mesh				40	438	467	
Lamp Black, Eagle Brand	0.476	0.165		40-150	166	176	6
Germantown				40	156	160	
Coal Dust	0.476	0.73		30-150	298	317	23
				30	265	282	
Iron Dust and Sand	0.377	1.14		30-150	517	550	23
				30	460	489	

of transverse thermal conductivity of iron stampings with pressure, but the apparatus did not lend itself readily to this, since the exact pressure applied could not be determined. It is interesting to note that the transverse conductivity of iron stampings can be increased from 3 to 4.5 times by painting the sheets with asphalt paint before putting them together. Consequently if the punchings in electrical apparatus could be assembled in groups, having a gum or other suitable material between the constituents so as to have better contact, the heat generated could be much more readily conducted away. The results for the longitudinal thermal conductivity of iron stampings were obtained by making up a form, 12 by 12 by 1.5 in. from strips 12 by 1.5 in. of each of the two kinds of steel mentioned. The strips were fastened tightly together by means of heavy bars and bolts. Each side of these were ground smooth and the thermocouples inserted in small grooves in the faces, the thermocouple junction being actually pinched between the sheets of the material.

By comparing the values found for soapstone and 0.015 in. paraffined fish paper by this method, it is seen that one inch of paraffined fish paper (made up of sheets) has a thermal resistance equal to 16 inches of soapstone. In Part I, it was seen that the same ratio was found to be 32 by means of Northrup's thermal bridge. The discrepancy is no doubt due to the loss of heat laterally in the bridge. This makes the slope of the curve, Fig. 4, much greater above the sample than below it. Consequently a larger ratio is obtained than would be the case were the temperature drop uniform along the apparatus. It is easy to show mathematically also that an apparatus, such as is depicted in Fig. 1, should be at least five times as large in diameter as it is long in order to be little influenced by loss of heat from the sides. As can be seen, no such relations existed between the dimensions of the apparatus.

It is interesting to see the effect a layer of dust would have upon the internal temperature of a piece of apparatus. Thus if a layer of coal dust is deposited upon a surface through which heat is passing, the temperature within the surface will be raised 0.001/0.003 or 1-3 degree C. for each watt of energy that

TABLE VI.—THERMAL CONDUCTIVITIES OF SHEET STEEL

Material	Thickness of Sample, Ins.	Direction of Heat Flow	Temp. °C.	Cal /Cm / °C /Sec. · 10^6	Watts /In / °C · 10^5	Temp. Coef. · 10^4
0.0172 In., M. A	0.415	Trans.	20	1370	1455	
Varnished			20-80	1430	1520	19
With Asphalt	0.420	Trans.	20	4710	5020	
Paint on Sheets		Trans.	20-80	4850	5160	10
Unvarnished	0.416	Trans.	40	1480	1570	
0.0172 In.			40-100	1580	1680	25
Same with	0.425	Trans.	40	6360	6750	
Asphalt Paint			40-100	6520	6930	9
W. A. Silicon Steel 0.014 In. Varnished	0.419	Trans.	40-80	1270	1350	16
Same Painted with Asphaltum	0.422	Trans.	40-80	4640	4920	10
Unvarnished	0.440	Trans.	20	1340	1420	
			20-100	1470	1560	25
Same Painted as Above	0.443	Trans.	20	4200	4470	
			20-100	4520	4810	17
0.0172 In., M. A. Sheet Steel Unvarnished	1.48	Long.	40-100	103000	109500	6
			40	101300	107700	
0.014 In., W. A. Silicon Steel Unvarnished	1.44	Long.	40-100	41800	44400	19
			40	39500	42000	

passes through unit area of the surface in the form of heat. This is on the assumption that there is but little difference between the loss of heat from the two surfaces.

SUMMARY OF RESULTS

1—Attempts made to use a "thermal bridge", recommended by Prof. Northrup, to determine the thermal conductivity of insulating sheet materials indicated that it was not satisfactory for this work.

2—Two "thermal meters", one of circular cross-section and the other of square cross-section have been found entirely reliable for the measurement of the thermal conductivity of sheet and other materials.

3—By putting vaseline, glycerin, glue, shellac or a similar material on the division between two surfaces, the thermal drop due to such division can largely be eliminated. This is particularly true for poor conductors.

4—The thermal conductivity has been measured for a large number of materials, both across and along the laminations. For poor conductors, the ratio of the longitudinal to the transverse conductivity varies from *2* for black bias cloth to 5.5 for mica tape.

5—The temperature coefficient of thermal conductivity has been measured whenever the experimental results justified doing so.

6—Of the electrical insulating materials tested, those containing mica have the best thermal conductivity.

7—As a thermal insulator, soft pine is the best of the woods tested. It is but little inferior to dark grey felt.

8—The transverse conductivity of iron stampings can be increased some three or four times by the insertion of some suitable material between the stampings so as to make better thermal contact. This is for a pressure of about 50 lbs. per sq. in. Nothing destroying the electrical insulation could be used however. By using something between sheets, using something between sheets, the ratio of the longitudinal to transverse conductivity could be reduced to *20* to *25* instead of *80* to *100*.

9—In general, the thermal conductivity of laminated products can be considerably increased by suitable impregnation, so as to get rid of the air film.

10—Oil soaking soft fuller board increases its thermal conductivity by about 50 percent.

11—The best thermal insulation for a given thickness of any material is obtained by using several thin sheets rather than a single sheet.

12—Results were obtained for longitudinal conductivity of iron stampings. 0.0172 in. carbon sheet steel is about 2.5 times better than 0.014 in. silicon sheet steel. Carbon sheet steel has a longitudinal thermal conductivity about 80 times the transverse, while silicon has but 32 times the transverse.

13—A layer of dust, say coal dust, upon the surface of a body will increase its internal temperature by 1/3 degree C. per watt flowing through unit area.

Manual Starters for Small Squirrel-Cage Induction Motors

C. K. Applegarth and H. D. James

SQUIRREL-CAGE induction motors, of five horse-power and less, are usually started by connecting them directly to the power supply without the use of a current limiting device, such as a resistor or transformer. The impedance of these small motors is sufficient to limit the current drawn at standstill to an amount which will not cause serious voltage disturbances to an ordinary power circuit. Standard practice has, in general, limited the size of motors started in this way to five horse-power, although, for some applications, 10 and 20 horse-power motors and occasionally even larger sizes have been started by connecting them directly to the line. When motors are started in this way, the controller consists of a device for connecting the primary of the motor to the power circuit and is usually called a "motor starter" or simply a "starter". The starter should be provided with a low-voltage device to protect the operator and machinery from injury due to the unexpected starting of the motor upon the restoration of voltage after a failure of power;

it should also be provided with an overload device to protect the motor against overheating due to excessive loads. If the overload device has a considerable time element, it can be adjusted close to the motor rating and afford protection against injury due to single-phase operation.

The starter should be rugged in construction and have sufficient arc-rupturing capacity to open the current taken by the motor when at stand-still. The construction should be the same as for standard controllers used with larger motors. Devices designed for other purposes very often do not have the contacts or mechanism rugged enough to stand the frequent operation to which the starter is subjected. It is, therefore, better to design the apparatus specifically for motor starting rather than to attempt to adapt other aparaus for this purpose.

The overload protection presents a special problem on account of the heavy starting current which is maintained for a large part of the starting period. Fig. 3 shows the curve of a squirrel-cage motor of average design. Curve *A* represents the torque, which is relatively small when the motor is at rest and increases to a maximum value close to full speed. The torque then rapidly decreases until it reaches zero at synchronous speed. Usually the motor operates at about 97 percent of synchronous speed, which gives a full load torque value of about half the maximum. Curve *B* represents the current, which is a maximum at the time of starting, and decreases in value gradually at first, the decrease becoming more rapid as the motor approaches its maximum torque value. If the torque exerted by the motor, when at rest, is sufficient to overcome the static friction and start the load, it will accelerate rapidly on account of the increase in value of the motor torque. Most applications require more torque to start than to accelerate the load, so that there is a large surplus torque available for acceleration, and motors of this type often accelerate to full speed in three or four seconds. During most of this accelerating period the current is considerably in excess of its normal value, so that the overload protective device, unless short-circuited, is subjected to this heavy current. Some starting devices have two positions, one for starting, in which the overload protection is short-circuited. Other devices use relays to obtain overload protection and provide these relays with dash pots to retard their operation. The time element

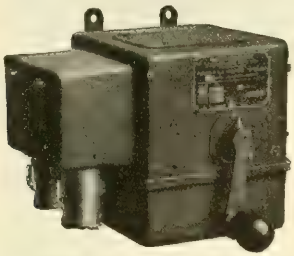


FIG. 1—10 HP MOTOR STARTER

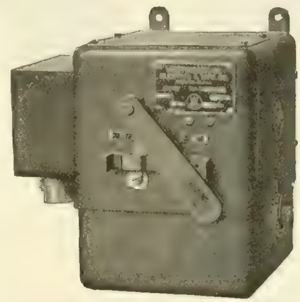


FIG. 2—25 HP QUICK MAKE AND BREAK STARTING SWITCH

Having contactors arranged to open and close with a quick positive motion independent of the speed at which the handle is moved. These starters are equipped with both low-voltage and inverse time element overload devices, so arranged that the switch cannot be held closed on overload. All live parts are totally enclosed in dust proof cases. In Fig. 2 the knob is removed to permit of shipper rod operation.

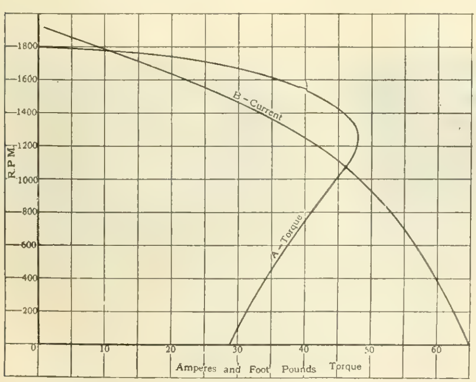


FIG. 3—INDUCTION MOTOR CHARACTERISTIC CURVES
Showing variation in torque and current during the acceleration of a 5 hp, squirrel-cage induction motor.

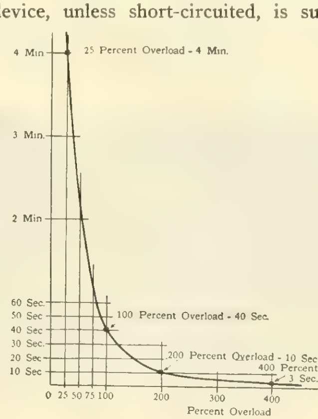


FIG. 4—RELAY CURVE
Showing the time required for the overload device to open the starter after an overload has been applied. The percentage of load is in terms of the relay setting and is usually higher than the full-load rating of the motor.

obtained with a dashpot relay of this kind is shown in Fig. 4, the horizontal line indicating the percent of current in excess of that required to trip the relay. The vertical lines show the time required for tripping after the current has been applied.

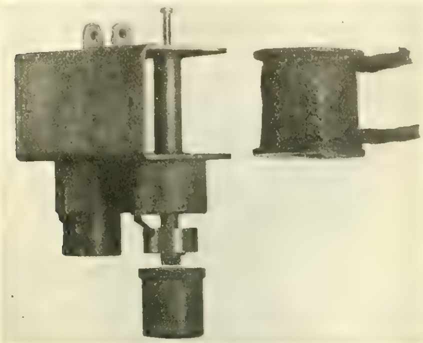


FIG. 5—OVERLOAD DEVICE FOR THE MOTOR STARTERS SHOWN IN FIGS. 1 AND 2

The calibration is indicated on the dashpot, the setting for the proper overload being obtained by screwing the dashpot up or down in the supporting sleeve. A vertical groove is made in the dashpot and a locking tip is so mounted on the supporting sleeve as to hold the dash-pot securely at any setting. The calibration is adjusted by bringing the proper mark to the bottom of the projection on the supporting sleeve; it can be changed quickly with one hand and without the use of any tools.

Most motors used for industrial applications are subjected to overloads for short periods of time. Ordinarily 25 percent overload can be carried for a considerable period of time without injuring the motor. It is, therefore, customary to set the overload trip so that it will operate close to this value. If we assume that it is set to operate at 125 percent of full load and that the current taken by the motor when at rest is five times the full load value, the relay will be subjected to a load which is equal to 5 ÷ 1.25, or four times its tripping value when the motor is first started. The curve shows that the relay has a time element of three seconds at this overload but, as the motor accelerates, the current decreases and the time element of the relay increases.

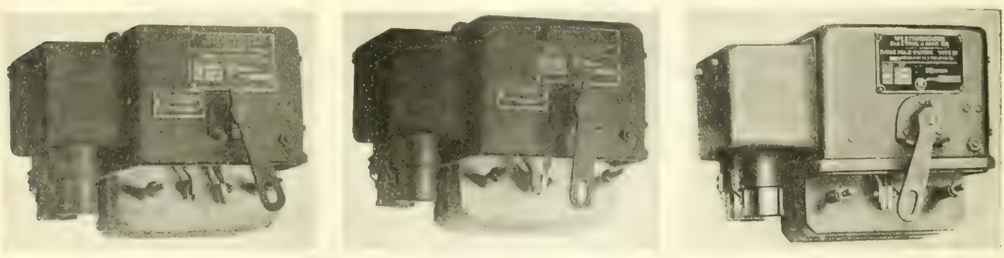


FIG. 7 MOTOR STARTER WITH TANK REMOVED

These three views illustrate the action of the contacts in closing and opening. The contacts first engage at the tip and then roll back to the heel which carries the current. In opening, the reverse operation takes place, and causes all of the arcing to occur at the tip. The rolling action prevents the contacts being welded together and lengthens their life.

If the motor can accelerate the load in four or five seconds the relay can be set at 125 percent of the full-load rating and start the motor without tripping. Experience shows that most applications for small motors have a load characteristic that permits the motor to start within this time interval, in fact, many applications are accelerated to full speed in three seconds or less, so that it is not necessary to short-circuit an overload relay of this design during the starting period; this results in a much simpler form of controller. A relay automatically resets itself after tripping and is therefore preferable to a fuse, especially for machine tool or other similar work where severe overloads for a very short time are common. The first cost of fuses is less than relays but renewing fuses is a continual expense and, unless properly protected, the workman is exposed to live parts of the circuit during renewal.

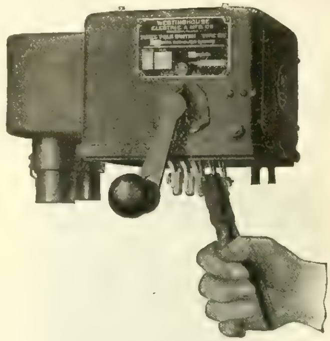


FIG. 6—THE CONTACTS ARE READILY ACCESSIBLE FOR ADJUSTMENT OR REPLACEMENT

Controllers of this type are usually required to have both low-voltage and overload protection, but it is sometimes desirable to omit one or the other, or perhaps both of these devices. It is, therefore, convenient to have the controller so designed that it will permit of these variations. A starter of this general type without the overload device is illustrated in Fig. 6. The overload trip is mounted in a small case which can be detached from the side of the switch. The low-voltage device is mounted inside the cover and may be omitted when not required.

It is desirable to enclose control equipment so that

live parts are not exposed or easily touched by operators or other persons. The arc rupturing parts should also be protected so that the flash cannot burn the operator or set fire to objects in the vicinity. It is an advantage to have the apparatus enclosed in a case which will exclude ordinary dust or moisture. The starters shown in the illustrations are all of this type. These starters are entirely self-contained, and the contact element trips free from the handle to prevent holding it closed on an overload. The switch compartment is provided with non-combustible barriers between adjacent sets of contacts and the tank is lined with an insulating material; this arrangement permits the use of the switch without oil. The lower part of the enclosure is made oil tight so that where combustible or explosive material exists in the atmosphere, oil can be used as an added precaution against igniting this material.

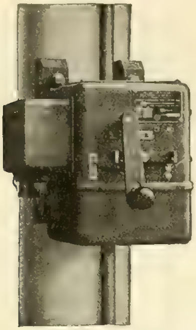


FIG. 8—METHOD OF CONNECTING THE MOTOR STARTER

Where the line wires enter from below and the motor wires from above, or vice versa.

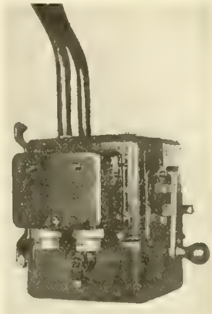


FIG. 9—A MOTOR STARTER WITH THE WIRES ENTERING THE TOP

FIG. 10—METHOD OF CONNECTING A MOTOR STARTER FOR OPEN WIRING

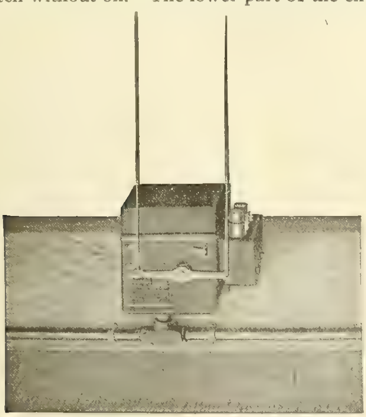


FIG. 11—A MOTOR STARTER MOUNTED NEAR THE CEILING

And arranged to be operated from the floor by pull cords.

The life of contacts depends largely upon their being closed, as well as opened, with a quick positive motion. On many applications the operator cannot be depended upon to move the controller handle in the most desirable manner. It is, therefore, a distinct advantage to arrange the contacts so that, even with a slow, uncertain movement of the handle, the contacts will close and open with a quick positive motion. An arrangement of this kind is usually known as a "quick make and break" device.

The method of obtaining this action in the switch shown in Figs. 1 and 2 is unique. The contacts are actuated by the movement of the operating handle, first to the *reset* position and then to the *on* position. The operating handle is connected to the contactors through a spring toggle mechanism which is so arranged that they will not remain in any intermediate position, but are either fully open or fully closed. As the speed at which the contacts open or close is determined solely by the spring, the correct functioning of the switch is independent of any carelessness on the part of the operator. This reset feature eliminates the possibility of a false start by an accidental movement of the starting handle.

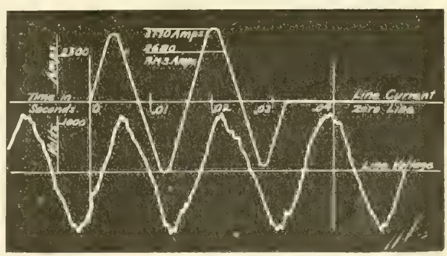


FIG. 12 OSCILLOGRAPH RECORD OF A TEST MADE ON A 25 HP MOTOR STARTER

Line characteristics, three-phase, 60 cycles, 750 volts, 55 percent power-factor, maximum 3770 amperes, root mean square 2680 amperes.

The general form of contactors is the same as that which has been proven successful in larger magnetic contactors; that is, they provide a combined rolling and wiping action which localizes all arcing at the tips and ensures a clean surface at the point of final contact.

This form of contactor has been proven by heavy steel mill and railway service to give long life under the most severe operating conditions.

Starters are usually mounted so that the handles are within reach of the operator. There are some installations, however, where it is more convenient to mount the starter close to the ceiling and operate it by ropes as shown in Fig. 11.

It is often desirable to place the starter on one end of a spinning frame, lathe or other device and operate it by means of a shipper bar or a lever. An attachment of this kind can be readily made by removing the knob from the handle and making a connection through a slot in the handle. However, where a small starting device is used and the operating handle is attached to a shipper bar, or other heavy moving device, stops should be provided on the shipper bar so that the hammer blow, at the time of operation, will not be transmitted to the frame of the starting device.

Safety stop buttons can be connected in series with the low voltage coil for stopping the motor. It is necessary on some applications to locate these buttons at safe points on or near the driven machinery for convenience or to afford the operator reasonable protection in case of accident.

Good practice makes it desirable to use conduit connections throughout an installation. This affords protection both against personal hazard and against fire, and presents a very neat appearance. An arrangement of conduit mounting for starters of this type is illustrated in Figs. 8 and 9. If open wiring is used the wire should be brought out through a standard fitting, as shown in Fig. 10.

A motor starter of this type may also be used to protect circuits feeding two or more motors and for other applications where overload protection is desired. It is often advantageous in an industrial establishment to keep the apparatus uniform to reduce the spare parts required for maintenance. Motor starters of this type have a considerable arc rupturing capacity. Tests were made upon the starters shown in Figs. 1 and 2, by connecting them to a load of 50 percent power-factor and 750 volts, with oil in the tanks. The load for the larger starter, as shown by the test, was approximately 2000 amperes; it ruptured this circuit successfully ten times at one minute intervals. The smaller starter ruptured 1000 amperes under similar conditions. The tests show that, where these starters are used in connection with motors, they afford a considerable circuit rupturing capacity in excess of that required for successfully starting the motor.

THE JOURNAL QUESTION BOX

OUR subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. The topics should be of general interest; information involving the specific design of individual pieces of apparatus is not supplied. Care should be used to include all data necessary for an intelligent answer.

A PERSONAL reply is mailed to each questioner enclosing a stamped, self addressed envelope as soon as the necessary information can be obtained. Anonymous questions cannot be considered. As each question is answered by an expert on the subject involved, and checked by at least two others, a reasonable length of time should be allowed before expecting an answer.

1827—Open Delta Connection—Of three single-phase, 500 k.v.a. transformers, connected delta-delta, 16 000 to 4000 volts, one 16 000 volt main burns off at X. What effect will this have on a rotary converter feeding from the 4000 volt side through three-wire, single-phase transformers (diametrical) 4000-208? What voltage will show on a voltmeter which reads normally 4000 volts? M.S.B. (PA.)

With the bus open, as shown by Fig. (a), two of the transformers are connected in open V while the other unit is idle. The output of the bank under

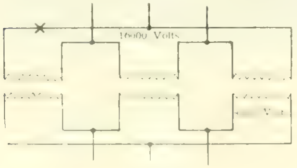


FIG. 1827(a)

these conditions is limited to 58 percent of that of the complete delta bank. The open V connection should give approximately normal voltage on the 4000 volt side, the only difference being a little greater regulation than was the case with the complete bank. This connection should not affect the rotary converter operation. J.F.P.

1828—Revolving Armature Alternator—Please explain the transformer action in the old style revolving armature, two-phase alternator. I have seen a 150 kw, 12 pole, 600 r.p.m. machine with the compensating field winding on the four laminated spokes of the armature. There are four primary windings, one in each lead to the four collector rings. However, there are only two secondary windings connecting with the rectifying commutator. It would appear that two of the primary windings are so remote from the secondary as to result in considerable magnetic leakage, and to serve somewhat as mere choke coils. Would it not be better to have the secondary turns equally distributed on all four spokes? A.S.P. (R.I.)

The old style compensating revolving armature had four arms, or poles, in the spiders. When wound for two-phase, a compensating winding was arranged as shown in Fig. (a). Here, A_1 and A_2 represent the primary compensating winding for one phase; B_1 and B_2 the primary for the other phase. A_1 and A_2 are so arranged that their fluxes are in opposite directions, as indicated in Fig. (a). The same holds true also for B_1 and B_2. Therefore, winding A_1 and A_2 must send its magnetic flux through the spokes, or arms, which carry windings B_1 and B_2. In the same way, fluxes B_1 and B_2 must go through the arms carrying A_1 and A_2. Thus a secondary winding placed on either pair of arms will be influenced by the resultant flux of both

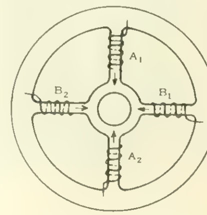
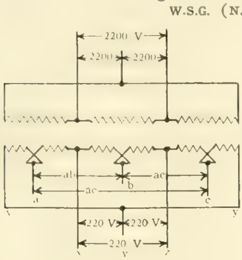


FIG. 1828(a)

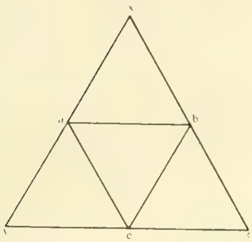
A and B phases, and the compounding action will be the resultant of the two phases. Neither winding acts as a choke coil, except for the very small leakage around the arms. This is necessarily of a minor degree, because the actual ampere turns used on the arms are very small. In consequence, equal distribution of the secondary turns apparently represents no particular gain, as proven by actual test. B.G.L.

1829—HALF VOLTAGE TAPS ON DELTA—In a three-phase, delta bank of transformers connected as in Fig. (a) please explain what voltage will be obtained at *ab*, *bc* and *ac*. What phase relation will these be to each other? Give vector diagram.

W.S.G. (N.H.)



(a)



(b)

FIGS. 1826(a) and (b)

An inspection of the vector diagram in Fig. (b) will completely answer this question with respect to both voltage and flux relations. It is obvious that the voltages between points *a*, *b* and *c* are one-half the voltages between points *X*, *Y* and *Z* and that voltage *ab* is in phase with voltage *YZ*, etc. C.R.R.

1830—INDUCTION MOTOR WITH OPEN SECONDARY—Considering a 200 hp, three-phase, 60 cycle, 2200 volt, wound rotor induction motor with the rotor locked and the slip rings disconnected from the secondary resistance, and full voltage applied to the stator. *a*—Would the voltage induced in the rotor winding be apt to break down the insulation between phases? In a machine of the above type that was acting peculiarly while accelerating, a short-circuit between rotor phases was suspected and so the secondary resistance was disconnected and an attempt made to start the motor against load with the rotor circuit open. *b*—Assuming the rotor winding had been O. K. would not the above plan very likely cause a breakdown between phases itself? *c*—Would the rotor have any appreciable torque with the rotor circuit open?

H.R.L. (WASH.)

a—The secondary windings, collector and brush rigging of wound rotor induction motors should be built with sufficent insulation to withstand the normal secondary voltage of the motor; that is the voltage induced between the slip rings with the secondary circuits open when full voltage is impressed on the primary with the rotor at rest.

b—Assuming the secondary insulation to be in good condition and the collector and brush rigging free from dust and moisture, the secondary insulation should not break down with full voltage applied to the primary and with the secondary circuit open.

If the primary circuit is closed or opened with the primary voltage at full value and the secondary open, the sudden changes of magnetic flux will induce voltages in the secondary which may be far in excess of the normal secondary voltage and these momentary high voltages may cause a breakdown of the secondary insulation or a flashover at the collector. Full voltage should never be impressed directly on or off the primary of a large induction motor with the secondary circuits open. In taking an open circuit saturation test on induction motors on a test floor, the voltage of the alternator is reduced to a very low value by inserting resistance in the exciter field, before connection is made to the primary of the motor. After connecting to the primary, the voltage of the alternator is then increased to normal value. Before the primary circuit is opened, the voltage of the alternator is reduced to a low value. *c*—The motor should not have any appreciable torque with the secondary circuits open. G.T.S.

1831—ARCING GROUND—We have two 8000 k. v. a., 11 000 volt, three-phase, water-wheel-driven generators, star connected, with ungrounded neutrals operating in parallel with other 2300 volt generators through a bank of transformers. The lines running from the station are 11 000 volt, three-phase, and while the main line is very well erected, insulated and kept free from trees, there is a branch line tapping the heavy main line that runs four miles along a highway. This line furnishes a small town with light and power services and is fused for 10 amperes in each wire, where it taps the main line. Along this branch line there are a great many trees that cannot be trimmed and frequently we are troubled with grounds and short-circuit. Is an arcing ground which might be caused by a wet tree limb on the branch line liable to set up any high frequency disturbances in the generators and cause insulation difficulties? The main transmission line, exclusive of the branch 11 000 volt line, is a double circuit line of only 6100 feet in length. Also would an arcing ground from one of our 11 000 volt conductors through a defective insulator be a dangerous condition to have on such a system? By this last we mean such as a continual static spitting through a defective bushing and over a damp piece of marble asbestos board or other similar material? C.T.M. (ME.)

Arcing grounds or defective insulators on a line of this kind should not cause any disturbance at the generator, except that which would be caused by sudden application of line potential from terminal to ground. Such potential should be withstood by the insulation if it is in good condition and clean, but possibly when the insulation has become old and dirty and has deteriorated, the potential might cause it to break down. Calculations indicate that the superposed oscillation set up by the fault will be of very high frequency, because of the low capacitance between line and ground and the damping of the oscillation will be high. If the 11 000 volt system involved a considerable amount of cable, the conditions would be different. If trouble is being experienced, it would be desirable to ground the neutral of the system, as this would prevent the rise of potential of the clear line to full line voltage, and would give insurance against the repeated oscillations which might occur now on the system because of its being ungrounded. A.W.C.

1832—RECHARGING FLASH-LIGHT BATTERIES—Is it possible to re-charge electric flash light batteries, and if so, what is the process?

P.L.M. (PA.)

It is possible to recharge dry cells of any type by passing direct-current through them in the opposite direction to the normal flow. This current should be kept relatively small, not over double normal load. While a fairly good freshening charge can be given a battery in this way several different times, thereby materially increasing its useful life, it is not possible to recharge such batteries repeatedly as is done with storage batteries, and the process is a wasteful and inefficient one. As such a battery can never be recharged to its initial strength, the purchase of new ones is usually advisable. C.R.R.

1833—INDUCTION MOTOR REVERSAL—We have a three hp, three-phase, 25 cycle, 750 r.p.m. squirrel-cage induction motor which operates an endless chain elevator which loads steel billets onto railroad cars. One of these billets jammed the elevator, whereupon the motor came to a dead stop and reversed its direction of rotation. On reversing, the fuses did not blow nor did the switch trip out. None of the phases are open as the motor always runs in the right direction when started up. We have since tried fixing one of these billets so that it stops the elevator on reaching the top and also on reaching the bottom after reversing. Nothing happens, except that the motor keeps reversing its direction of rotation until some one removes the obstructions, or trips the switch. How can you account for this strange action?

C.P. (ONTARIO)

There are two possible explanations to this which depend on the speed at which the motor operates in the reverse direction and whether a starter is used or not. *a*—If the reverse speed is the full speed of the motor and a starter is used, the cause is probably outside of the motor and the explanation is as follows: The motor is started as a three-phase machine by the starter but, when thrown on the line, one contact is probably bad and the motor operates as a single-phase machine. Since it starts as a three-phase machine its direction of rotation at start is definite, but as a single-phase motor its direction of rotation is determined by the direction in which it is started. Also as a single-phase machine it will not have as high a maximum torque as if it were on three-phase. When the billet jams, the motor stalls due to its decreased torque when running as a single-phase machine and the back lash in the gears give the

rotor a start in the opposite direction. As the motor primary is still on single-phase, it tends to run the way it gets started, so that it reverses until the billet jams at the other end, when it goes through the same cycle. *b*—If the reverse speed is very slow and no starter is used, the explanation is as follows:—Induction motors and especially those with a small number of poles have a tendency to have points of low torque in their speed torque curves. If this condition is present in this motor, and the rotor were suddenly reversed mechanically by the back lash in the machine when the billet jams, it would run in the reverse direction at a very slow speed and carry a small load. C.W.K.

1834—MAGNET COIL—Given the number of turns of wire and ohms resistance (measuring on direct-current) of an alternating-current magnet coil which is to be connected across a 220 volt, 60 cycle line, how would you determine the number of turns of wire on a coil for the same magnet switch for use on 110 volts, 60 cycles; also how would you determine the number of turns of wire to be used on 220 volts, 40 cycles? W.W.M. (N.Y.)

Changing only the coil on the magnet switch and using the magnet to do the same work, that is, to use same magnetic circuit and keep the same flux density, the number of turns in the operating coil is directly proportional to the voltage and inversely proportional to the frequency. Knowing the number of turns for 220 volts, 60 cycles, the number for 110 volts, 60 cycles will be one-half the former, and the number of turns for 220 volts, 40 cycles will be 60÷40 or one and one-half times that for 220 volts, 60 cycles. Current and size of wire will vary inversely as the number of turns. W.C.G.

1835—STARTING TROUBLE WITH INDUCTION MOTOR—We have a three-phase motor with a wound rotor for starting with resistance in series. When this resistance is cut in it always starts O. K. But when the resistance is all cut out it starts at some places and not at others. Why is it that when this resistance is all cut out on this wound rotor that it will start in some places and not at others until one happens to move the rotor, when it will then start O. K. once more? F.G. (MICH.)

A wound rotor motor usually has a relatively low resistance in the rotor and when this is short-circuited, the starting torque is low. When this low starting torque is further decreased by increased magnetic leakage due to the torque remaining is often insufficient to overcome the magnetic locking action of the rotor teeth when a large number of rotor and stator teeth are lined up opposite each other. This condition is true of all wound rotor motors in greater or lesser degree, when the rotor is short-circuited. It is not noticed when the rotor resistance is relatively high as in small motors. In larger motors, where the resistance is usually smaller, the conditions vary with different designs C.W.K.

1836—TESTING ELECTROLYTE—What test can be given the ammonia solution which is used in electrolytic lighting arresters to determine if it is suitable for use, after it has been standing in the original glass carboys for two or more years and not opened? E.W.R. (KANS.)

Test two samples for sulphates and chloride, in one case use barium chloride and in the other silver nitrates. If precipitates are obtained, the result is positive. Sulphates and chlorides, except in small quantities, have a very deleterious effect on electrolyte. This test can be made by a good druggist. G.C.D.

1837—DETERMINING FAULTS IN INDUCTION MOTORS—Please give methods of locating faults in the stator coils of three-phase alternating-current motors and also in the rotors with and without a short-circuiting device. G.L.H. (ILL.)

The faults of a stator winding of a three-phase, alternating-current motor are in general, a grounded coil, an open coil, or a short-circuited coil. A ground can be determined by measuring the insulation resistance of the winding by the use of an ohmmeter or megger or making a puncture test with an insulation testing transformer. An open circuit in a winding where the coils are all connected in series may be determined by trying out each phase of the motor for a circuit by the use of an ordinary hand magneto. To find the particular coil in the phase that is open, the end connections of the windings must be opened up and each coil tried out separately. An open circuit in a winding where a series-parallel connection of the coils is used, must be determined by another method since an open circuit in one of the coils would not open up the phase. By measuring the resistance across each phase of the winding, an unbalanced condition will be found if one of the coils is open. A short-circuited coil will heat considerably when normal voltage is applied to the motor, and consequently the insulation of the coil will get hot and burn, so that the coil that is short-circuited can generally be located by observation. In small motor windings, in which the coils are not formed before the motor is wound, a turn or two may be short-circuited. A fault of this nature will not burn out unless the motor is run for sometime, and must be determined by measuring the no-load input to the motor. Due to the excessive input that the motor will take under this condition, the temperature of the motor will rise considerably above the temperature rating under full load. Three-phase alternating-current motors have either a squirrel cage or wound type rotor. Any fault of a squirrel cage rotor usually lies in improper soldering of the copper bars to the resistance rings. It is difficult to determine whether a rotor is soldered improperly and requires a comparison of the values calculated from the original design with the actual values obtained under test. The faults of a wound rotor are generally the three mentioned in respect to the stator winding. A grounded coil, and an open circuited coil in the rotor winding can be determined by the same methods, as in the stator winding. A short-circuited coil can be determined by applying normal voltage to the primary winding, leaving the rotor winding open at the rings. If one of the coils of the rotor is short-circuited, the rotor will rotate at a slow speed, accompanied by a low pitched grinding noise. The coil which is short-circuited will get hot and the insulation will burn so that the fault can be located by observation. A short-circuited coil in the wound rotor used in a single-phase repulsion motor, having a short-circuiting device, can be determined by lifting the brushes and connecting the stator winding to the line. If the rotor winding is short-circuited the rotor will assume the same fixed position each time voltage is applied to the stator winding, with the rotor in various positions. W.O.L.

1838—FREEZING BATTERIES—I have been looking for a thorough treatise on the effects of freezing on a storage battery. This subject is usually dismissed with a few words, such as throw the plates away if they have been frozen and a table showing the freezing point of different electrolytes. I would like to see the proposition analyzed, the reason why chemical action is caused by freezing the plates, if there is any and what methods have been tried to repair or correct the plates or battery that has been frozen. B.D. (IDAHO)

If, after the battery has been recharged, the active material is intact, the battery will continue to give good service. However, when the battery is frozen, the expansion of the active material and grid being different, there is a tendency for the pellets of active material to become loosened from the grid, causing what is known as shedding. If this occurs there is no remedy, and the battery should be replaced with new positive plates. In any case, there is never any marked effect upon the negative. It is our opinion that there is no chemical action in a battery freezing, but that the damage is purely physical. That is, the hard rubber jars may be broken and the active material may be forced from the grids of the plates. K.W.G.

1839—MOTOR DRIVE—The writer has been asked to make a report on the advisability of driving line shafting, requiring approximate 55 hp, by using two 30 hp, 60 cycle, 550 volt induction motors instead of one 60 hp, motor, the object being to make use of two 30 hp motors not in use. The motors referred to are the same make, speed, etc. Kindly advise what results might be expected from either belt, chain or direct drive. J.B. (ONTARIO)

There should be no difficulty in using two 30 hp motors to drive a line shaft requiring approximately 55 hp. For belt drive all that is necessary is to be sure that the motor pulleys are of the same size and the driven pulleys on the line shaft are of the same size. The same applies to a chain drive, i.e., the driving pinions must have the same number of teeth and the driven gears on the line shaft must also have the same number of teeth. Direct drive can be used, provided the shaft operates at the speed for which the motors are designed. Also the motors must have the same speed regulation over their working range. G.B.

THE ELECTRIC JOURNAL

RAILWAY OPERATING DATA

The purpose of this section is to present accepted practical methods used by operating companies throughout the country

The co-operation of all those interested in operating and maintaining railway equipment is invited. Address R. O. D. Editor.

DECEMBER 1919

Systematic Inspection of Car Equipments

Too much stress cannot be laid upon the importance of regular systematic inspection of street railway rolling stock, as a result of which clean dependable cars are always available to meet the demands of the transportation department and failures on the road and number of pull-ins are reduced, with a consequent better maintenance of schedule and car service.

A SUGGESTED SYSTEM

In submitting a system of inspection for railway equipment, it is fully realized that no one definite scheme will apply to all properties; also that whatever suggestions are made along this line will not entirely meet the demands of the many varying conditions under which operating men must keep their equipment on the road. However, it is fair to assume that by having a definite program of inspection outlined to meet average conditions existing in the railway field, some operators will be benefited by using this plan as a guide in re-arranging or planning a system to meet their own requirements. With this in view, the following outline is suggested for regular and systematic inspection of railway equipment:

PERIODS	SERVICE	TIME	MILEAGE
Daily	City	Each day	90 to 100 miles
	Interurban	Each day	180 to 200 miles
Light	City	8 to 10 days	800 to 1000 miles
	Interurban	8 to 10 days	1600 to 2000 miles
Heavy	City	Once per year	30 000 to 35 000 miles
	Interurban	Once per year	60 000 to 80 000 miles

DAILY INSPECTION

1—Cars should be run over the pit and the brake rigging and shoes should be inspected and repaired, if the parts are found defective or badly worn.

2—All minor defects of cars and equipment reported by the crew, such as broken glass, faulty doors, bad trolley wheels, hot bearings, defective wiring, loose electrical contacts, faulty control operation, etc., should be repaired so as to put the car in good operating condition.

3—On some types of motors, the bearings will require oiling every night.

LIGHT INSPECTION

1—Run the cars into the inspection shed and carefully examine their mechanical details, such as trucks, brakes, air piping, etc.

2—Inspect the electrical equipment, wiring, etc., and check for grounds and faulty operation.

3—Motors, controllers, switch groups and all auxiliary apparatus should be cleaned thoroughly by means of dry compressed air.

4—Necessary repairs to the car body and the details of the car should be made.

5—All wearing parts of the equipment, such as bearings, commutators, brushholders, carbons, trolley wheels, control contact tips, and drum rings should be overhauled and put in smooth running condition.

6—Gears, pinions, wheels, axles, trucks and brake details should be inspected and all worn or broken parts repaired or renewed.

7—Examine the arc chutes, electrical insulation and the car wiring, to see that they are in safe operating condition.

8—All covers on electrical apparatus and on motor bearings and journal boxes should be made to fit tightly, so as to keep out dust, snow and water.

9—Tighten all bolts on motors, gear cases, trucks, etc., and make all necessary repairs so that the cars will leave the inspection shed in such condition that they will require no further attention (other than that which is provided for by the daily inspection), until the next regular inspection period.

10—Cars that are equipped with the more modern motors, having oil and waste lubrication, if oiled at this time, should require no further lubrication for the next ten days or two weeks.

HEAVY INSPECTION OR GENERAL OVERHAULING

These periodical overhaulings of such parts as the armature and axle bearings, pinions, gears, wheels, truck details, etc., should be determined by the estimated life of such parts, this life depending upon the electrical and mechanical design of the apparatus and its service conditions. With some equipments, it might be advisable and more economical to shorten the time of overhauling—but under extreme conditions only should the time be extended beyond the one-year limit.

Car Body—

1—Car body should be lifted from trucks and all electrical equipment removed, cleaned and overhauled.

2—Car body should be washed and all necessary repairs made to frame, roof, floors, platform, steps, bumpers, etc.

3—Car body should be painted at least every other general overhauling period.

Car Details—

1—Windows and deck lights should be removed, washed, repaired and the woodwork painted.

2—All seats should be cleaned and overhauled; if cane, they should be thoroughly scrubbed.

3—Light fixtures and heaters should be examined and put in good condition.

4—Fare registers, safety devices and all other car details, should be inspected and repaired.

Trucks and Details—

1—All parts of the truck and brake rigging should be carefully gone over and the badly worn hangers, pins, bolts, chafing plate, truck brake levers, and brake heads, should be repaired or replaced.

2—Truck side and center bearings should be rigidly attached to the bolster.

3—Height of bolster should be checked by the standard gauge supplied for this purpose.

4—New brake shoes and turnbuckles should be supplied, if these parts are badly worn.

5—Adjust brake release spring.

6—Wheels should be checked for diameter and flange wear, and either turned down or replaced by new ones, if necessary.

7—Pairs of wheels should be kept to the same diameter to prevent crowding one rail or the other, with a consequent destruction of flanges and an increased train resistance.

8—Diameters of pairs of wheels on the same car should not vary more than one-quarter inch; otherwise, the motor on the larger diameter wheels will be overloaded.

9—Gears should be checked and renewed, if they will not last until the next overhauling period.

10—Journal boxes, covers, bearings, check plates, etc., should be inspected and removed, if badly worn or broken.

11—Axles should be checked in a lathe, and if bent they should be straightened, or replaced by new ones.

12—If axles are badly worn, or have run their predetermined maximum mileage, replace by new ones.

13—Axle collars should be tightened and checked for proper clearances.

Air Brakes and Piping—

1—With pressure in the system, the gauges in the two ends of the car should not vary, one from the other, more than five pounds.

2—Governors should be adjusted to cut in at fifty-five pounds and to cut out at 70 pounds for city service and 85 to 100 pounds for interurban service.

3—Check the pop valve and adjust it so that it will operate at approximately 10 to 15 pounds higher than the cut out pressure on the governor motor.

4—Governor, whistle, air cocks, engineer's valve, triple valve, etc., should be put in first-class condition and given an operating test.

5—Test the air emergency equipment.

6—Inspect the dust collector, removing all deposited dust.

7—Examine the compressor motor switches and fuses, and put them in good operating condition.

8—Inspect the dash hose connections and hose couplings.

9—Full air pressure should be applied to the brake cylinders in order to check the piston travel, which should be limited to two and one-half inches at each end.

10—Oil and dirt should be blown out of all piping.

11—With pressure on the system, check for leaks and repair all defects.

12—Remove all dirt accummulation from the compressors, with compressed air.

13—Inspect the compressor motor brushholders and see that they work freely. If the carbons are badly worn or broken, furnish new ones.

14—Check the armature clearances with the gauge provided. If the bearings are badly worn, replace them with new ones.

15—All windings should be tested for grounds. If O. K., paint with a good grade of insulting varnish.

16—Operate the pump with doors open, and check for unusual sounds which would indicate worn bearings or defective valve operation.

17—The compressor gears and pinions should be examined to make sure that they are in condition to operate until the next inspection period.

Electrical Equipment—

Main Motors—

1—Motors should be opened up, armature removed and field coils taken out, and the inside of the motor frame cleaned out and painted, using an air-drying insulating paint.

2—Test field coils for short-circuits and grounds, thoroughly overhaul, paint and replace them in frame.

3—See that the wiring around frame, leads, bushings, and connections are in first-class condition; that they are well cleated and that there are no loose connections.

4—Clean the brushholders and replace badly worn parts and broken shunts.

5—Renew carbons, if worn or broken.

6—Bearings should be checked, and if worn or defective, rebabbitt or replace with new bearings.

7—Armatures should be thoroughly blown out by dry compressed air, and tested for grounds, open and short-circuits.

8—Inspect all bands, and if found loose or broken, reband. It is considered advisable to reband a newly wound armature after about one year's service, as bands tend to become loose, due to the stretch of the wire at high speeds and the shrinkage of the insulation, when subjected to excessive temperatures.

9—Commutators, if badly worn, should be turned and reundercut. Front V rings should be cleaned of all carbon dust and oil, and thoroughly painted.

10—Armatures should be painted and assembled in the motor frame. Approximately every second year the armature should be dipped in an insulating varnish and baked.*

11—If it is a split motor, be sure that the housings or bearings are a clamping fit between the halves of the motor frame.

12—See that all motor frame bolts are tight and that they are secured by lock washers.

13—Oil box covers should fit tightly so as to exclude dirt, snow and water. Remove all dirt that would prevent the covers from making a good fit.

14—Pinions should be inspected and if badly worn, they should be replaced.

15—Gear cases should be cleaned and examined for cracks and breaks. If found defective, replace with new ones, or have them welded. When replacing, they should be bolted tightly to prevent all movement and consequent wearing at the supports.

*See Railway Operating Data for April, 1918.

Control—

1—Controllers, main switches, line switches, switch groups, reversers, circuit interrupters, etc., should be carefully inspected and thoroughly cleaned out.

2—All badly worn fingers and segments should be replaced.

3—Contacts that are badly burned, should be filed smooth and adjusted, or replaced by new ones.

4—All charred insulating surfaces should be scraped and shellaced.

5—Tighten up bolted connections.

6—Test all valves and, if leaky, regrind them.

7—Inspect and lubricate all piston leathers.

8—Overhaul the circuit breakers, test for grounds, and check the setting of the circuit breaker with an ammeter,so as to protect the remainder of the equipment against excessive overload.

9—Grid resistors should be thoroughly cleaned of all dust and dirt.

10—Tighten up all bolts and replace cracked or broken grids.

11—Examine the junction boxes, receptacles etc., and see that all connections are tight and any broken wires repaired.

12—Current limit, over-speed, and over-voltage relays, etc., should be gone over, cleaned, repaired and properly adjusted.

Details—

1—Trolley wheels should be properly lined up and thoroughly lubricated. This is very important, as it will increase the life of the wheels.

2—All movable parts of the base should be inspected and well lubricated.

3—Springs should be adjusted to give approximately 25 to 35 lbs. pressure between the wheel and trolley wire.

4—Collector shoes with copper contact strips, also those that have steel contact surfaces, should be inspected and lubricated with a mixture of heavy grease and graphite.

5—Pantagraph contact pressure should be adjusted to approximately 25 pounds.

6—Inspect all nuts to see that they are tight and that they are provided with lock washers.

7—Taper pins are to be checked to see that they fit securely.

8—All moving parts should be oiled, and the exposed parts painted.

9—Piston leathers of pantagraph cylinders should be inspected and lubricated, the same as those on unit switch groups, so that the leather will not become sluggish and permit leakage of air.

10—Check the air connection union to see that the diaphragm is in place to protect the pantagraph from being damaged when raised or lowered.

11—Lightning arresters should be gauged and tested to make sure that they are in good working condition.

12—Storage batteries should be examined for broken plates, defective separaters and loose connections. Test the electrolyte for proper density and see that it covers the top of the plates.

13—Check and verify all control, heater, light and push-button circuits, and repair any defective wiring. See that all contacts are tight.

14—Stove motors should be examined, cleaned and lubricated, and the brush holders should be fitted with new carbons.

15—If main car wiring is not in conduit, go over it carefully to see that it is well cleated and secured from chafing. Repair all damaged parts and paint with heavy asphaltum paint.

In replacing worn parts, during the general overhauling, it may be necessary to remove parts that have not served their usefulness. These partly worn pieces can be used in making repairs during light inspection periods.

It is very important in connection with this work that the supervision of the light inspection and general overhauling of equipment be under the same directing head, so as to eliminate any question of responsibility. J. S. Dean.